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Prepared by the

Research Management Committee:

Walter W. Heck, Chairman
O. C. Taylor, Associate Chairman
Richard M. Adams
Joseph E. Miller
David T. Tingey
Leonard H. Weinstein

Senior Scientists:

R. G. Amundson
A. S. Heagle
D. A. King
R. J. Kohut
L. W. Kress
J. A. Laurence
A. S. Lefohn
V. M. Lesser
J. R. Miller
G. E. Neely
P. J. Temple

and

Statistical Consultant:

John O. Rawlings

July 1985

Project Officer

David T. Tingey
Air Branch
Environmental Research Laboratory
U. S. Environmental Protection Agency
Corvallis, Oregon 97333

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CORVALLIS, OREGON 97333

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This is the fifth annual report of NCLAN. Research for 1984 involved performance of a preliminary economic assessment of simulated changes in ambient O_3 on U.S. agriculture using recent NCLAN response data for six major crops. The economic effects of four hypothetical ambient O_3 levels are measured and compared with a 1980 base situation. The results are derived from an ecomomic analysis based on a U.S. agricultural sector model that includes major crop and livestock production as well as processing and export uses. The agricultural sector model is a price-endogenous mathematical programming model that translates the yield changes suggested by NCLAN plant scientists, statisticians and meteorologists into estimates of economic consequences of O_3. This economic assessment overcomes many of the data problems of earlier assessments.

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ABSTRACT

The National Crop Loss Assessment Network (NCLAN) consists of a group of organizations cooperating in field work, crop modeling, and economic studies to assess the immediate and long-term economic consequences of air pollution on crop production. Two primary objectives are 1) to define relationships between yields of major agricultural crops and doses of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and mixtures of these pollutants under realistic field conditions and 2) to use these relationships to assess the economic consequences of exposure of crops to ambient levels of these pollutants throughout the United States. The strategy for completing the economic assessment includes developing and extrapolating a comprehensive set of dose-response data for use in an economic model to estimate effects of crop yield changes on producers and consumers.

This is the fifth annual report of NCLAN, covering the period from 1 February 1984 to 31 January 1985. During this period, research progress has been made in understanding the interacting elements related to air pollution-induced crop loss and integrating them with the economic assessment effort. This was accomplished by developing O_3 dose-crop yield functions for soybean, clover-fescue and alfalfa as affected by soil moisture; likewise O_3 functions for red clover-timothy and alfalfa as affected by SO_2. Additionally, vertical O_3 gradients over a soybean canopy, establishment of a data library in preparation for program data synthesis, and further evaluation of the effect of soil moisture on dose-response relationships for soybean are reported. An evaluation of the Kriging technique for extrapolating O_3 concentrations across the country and a preliminary national assessment of the economic impact of O_3 on U.S. agriculture are highlighted. A complete listing of NCLAN publications is included.

Davis soybean were grown at Raleigh, NC under adequate or less than adequate soil moisture and exposed to six concentrations of O_3 for 7-hr/day from shortly after emergence until mature. Biweekly harvests were made to measure growth rates, assimilate partitioning, and nitrogen and carbohydrate metabolism. Seed yield was measured at maturity. The drought-stress treatment caused a 22% decrease in yield but did not significantly affect plant response to O_3. The predicted yield decrease caused by O_3 at concentrations which occurred in Raleigh, NC during 1984 was 13%. Results suggest that O_3 and water stress decrease levels of starch, soluble sugars and nitrogen compounds in vegetative tissues.

A ladino clover-tall fescue mixture was grown at Raleigh, NC in the field and exposed for 12-hr/day from April to October to six different concentrations of O_3 at two soil moisture levels (adequate and less than adequate). Plants were harvested and species were separated and weighed throughout the season whenever they regrew to a height of 25 cm. In-depth biochemical analyses for mono-, oligo-, and polysacharides as a measure of energy reserves were performed on shoots and roots of both species. The moisture stress treatment caused a decrease in yield of 10% for clover and 8% for fescue. Ozone decreased clover yield and increased fescue yield.

The increased fescue yield probably resulted from decreased competition from clover. The moisture stress did not significantly alter response to O_3.

Alfalfa (Medicago sativa L.cv. WL-514) grown in open-top chambers in Shafter, CA was exposed to five levels of O_3 and two levels of water stress in a completely randomized factorial experiment. Ozone was proportionally dispensed from 19 March to 10 October, 1984, whenever ambient O_3 concentrations exceeded 0.03 ppm. Alfalfa was harvested seven times during the O_3-dispensing season. Yields of both normally irrigated (NI) and water-stressed (WS) alfalfa were significantly reduced by O_3. Seasonal yield of NI plants was significantly inversely correlated with the square of the seasonal 12-h O_3 mean. Yield response of WS plots to O_3 was significantly linear, and a "protective effect" of water stress was observed at the highest O_3 concentrations but not at ambient O_3 concentrations. Seasonal yields of NI plants in non-filtered (NF) chambers were reduced 4.5 per cent relative to NI plants in charcoal-filtered (CF) chambers. Seasonal yield of NF plots in the WS treatment averaged 12.6 per cent lower than CF-WS plots. These results were discussed in relation to the timing of O_3 episodes and the physiological status of the plant as influenced by the timing and duration of drought stress episodes.

A mixed forage crop of red clover and timothy was exposed at Ithaca, NY to four concentrations of both O_3 and SO_2, alone and in combination, to evaluate treatment effects on crop yield and physiology of red clover. Exposures were conducted from June 28 through September 28. Two harvests were conducted to evaluate effects on yield; physiological studies were conducted throughout the exposure period. Exposure to increasing concentrations of O_3 resulted in decreases in both stomatal conductance and photosynthesis in red clover as measured by $^{14}CO_2$ fixation. In general, as red clover leaves aged their rates of photosynthesis declined and the differences in rates between treatments increased. Reductions in chlorophyll content were found only in the two highest O_3 treatment levels. Exposure to the lowest level of SO_2 appeared to induce stomatal opening in red clover while higher levels produced stomatal closure. Although sampling procedures made it difficult to compare the effects of SO_2 on photosynthesis, it appeared that SO_2 reduced photosynthesis only in one exposure at 0.80 ppm. Plants exposed to low and medium levels of SO_2 tended to have chlorophyll contents higher than those in unexposed plants. Both Weibull and linear dose-response functions were produced. In the linear function, the percent of clover in the crop stand was a significant covariate.

A spring-seeded stand of alfalfa (WL-312) was exposed at Argonne, IL to O_3, SO_2, and $O_3 + SO_2$ mixtures during August and September of the establishment year. No apparent effects of O_3 or SO_2 were noted on yield. Overall alfalfa growth was poor, however, probably due to any or all of the following factors: drought, leaf-rust infection, or shallow heavy soil. There was enhanced foliar injury at the highest O_3 treatment (0.083 ppm, 12-hr seasonal mean) and nematode populations were significantly increased at the highest O_3 treatment.

The effect of vertical position in open-top chambers on O_3 concentration was tested for different horizontal positions related to two rows of full-grown soybean. The same was done within and over a soybean canopy in the open. The test was performed for a nonfiltered-air chamber with approximately 0.05 ppm of O_3 added to nonfiltered ambient air and for a nonfiltered-air chamber with no O_3 added. For tests with O_3 added, O_3 concentrations decreased with increased height. When O_3 was measured between soybean rows at the center of the chamber, the mean difference between heights of 0.3 and 1.2 m was only 3%. However, directly centered over and within a soybean row, the comparable value was 11%. For tests with no O_3 added, the O_3 concentration, as a percentage of ambient, was the same at all heights. This percentage was 92% at the chamber center and 99% directly over the soybean row. In the open field the O_3 concentration at 0.3 m was about 10% less than at 1.2 m.

Independent quality assurance audits for air pollutant analyzers and system evaluations for biological measurements indicated all data were collected in compliance with NCLAN quality assurance requirements.

Data from NCLAN experiments is being stored for ready retrieval by all NCLAN participants. Plant response data and environmental data will be used in statistical modeling to test the adequacy of available models and to consider new statistical approaches. Results will be utilized in recommending future research and experimental designs. Data may also be used to develop several levels of simulation models for regional and national assessments.

A model was constructed to estimate the impact of moisture stress on soybean losses caused by O_3. The model simulates the effects of moisture stress and O_3 exposure on crop transpiration and uses empirically derived relationships between dry matter yield and seasonal transpiration to estimate yield. The model predicts decreased O_3 impacts on yield when moisture stress limits yield. Potential sources of error involve both the magnitude of the drought-O_3 interaction and the model estimation of moisture stress impacts on yield without the O_3 interaction. To evaluate the latter source of error, model results were compared to moisture stress impacts on regional yield estimated by Control Data Corporation (CDC). The CDC estimates were derived with a model designed to predict large area soybean yields which was validated against reported county yields. Moisture stress effects on yield predicted by the O_3 x water stress interaction model were highly correlated with CDC predicted effects, but CDC predicted greater moisture stress impacts on yield than did the interaction model. To account for such biases in estimating drought impacts, the general model relationship between O_3 sensitivity and drought depression of yield was used in combination with the regional drought impacts estimated by CDC to produce regional estimates of the change in crop response to O_3 caused by drought. The moisture stress effects on yield predicted by CDC were patchily distributed in 1980 and hence the expected O_3 x water stress interaction was also patchily distributed. The mean soybean response to O_3 for 1980 was reduced by 20% from the expected adequately watered response, but these model predictions have not been validated.

Economic assessments can provide information with which to compare the efficiency and equity of alternative policies and actions. Research for 1984 involved performance of a preliminary economic assessment of simulated changes in ambient O_3 on U.S. agriculture using recent NCLAN response data for six major crops. The economic effects of four hypothetical ambient O_3 levels are measured and compared with a 1980 base situation. The results are derived from an economic analysis based on a U.S. agricultural sector model that includes major crop and livestock production as well as processing and export uses. The agricultural sector model is a price-endogenous mathematical programming model that translates the yield changes suggested by NCLAN plant scientists, statisticians and meteorologists into estimates of economic consequences of O_3. This economic assessment overcomes many of the data problems of earlier assessments.

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SECTION I

INTRODUCTION

The current ozone (O_3) secondary National Ambient Air Quality Standard (NAAQS) is based, in part, on vegetation effects information presented in the "Air Quality Criteria for Ozone and Other Photochemical Oxidants" (1). The most current and indepth review for sulfur dioxide (SO_2) is found in the "Air Quality Criteria for Sulfur Oxides" (2). These reviews illustrated a need for additional field studies on the effects of exposure on economically important crops to support evaluation of the economic impact of O_3 and SO_2 on agriculture.

The National Crop Loss Assessment Network (NCLAN) is a coordinated national program of field and laboratory studies, crop modeling, and economic assessment efforts initiated by EPA to address the significance of crop losses caused by air pollution and to aid in the establishment and justification of the secondary standards (NAAQS). The NCLAN research is directed toward understanding the biological effects of air pollution on crops in the ambient environment, and the economic significance of these relationships.

Thus far, the program has focused primarily on the effects of O_3 on agronomic crops, although some research has incorporated SO_2 with O_3 and a few studies were done with SO_2 and nitrogen dioxide (NO_2). However, no information has been generated on effects of O_3 on perennial plants, including ornamentals, fruits, and forest species.

A Research Management Committee (RMC) represents the six air pollution research programs within the U.S. (Table 1.1.) and plans, manages, and executes the NCLAN Research Plan. The program objectives, approach, and organization are discussed in detail in Heck et al. (3-6), Adams and Crocker (7), and Kohut et al. (8).

The NCLAN program components (e.g., regional pollutant dose-yield response evaluations, pollutant/environmental interaction studies, physiological and growth studies, crop loss modeling, and economic modeling) have been coordinated to provide a systematic flow of information needed to conduct a national economic assessment of the effects of air pollutants on U.S. agriculture. A network of four field test sites (Ithaca, NY; Raleigh, NC; Argonne, IL; Shafter, CA) are established in four regions (Northeast, Southeast, Central States, Southwest) that contribute significantly to the production of major crops and have actual or potential pollution problems. At these test sites, normal crop cultural conditions are maintained under ambient and simulated air pollution regimes. In addition, crop modeling and economic assessment programs are situated in the Northwest at Corvallis, OR. From 1981 to 1983, a fifth site was operated in Beltsville, MD and from 1981 to 1982 a sixth site was operated at Tracy, CA.

Thus far, the NCLAN field experiments have concentrated on completing O_3 dose-crop yield response data sets for the crop species of greatest economic importance. Data sets have been generated for alfalfa, barley,

Table 1.1. Site locations, regional coordinators, and senior scientists[a]/[b]/[c]/

	Site Location	Regional Coordinator	Senior Scientists
1.	Northeast Regional Crop Loss Assessment Program (NERCLAP)	Leonard Weinstein Boyce Thompson Institute Ithaca, NY	Robert G. Amundson Robert J. Kohut John A. Laurence
2.	Southeast Regional Crop Loss Assessment Program (SERCLAP)	Walter W. Heck, USDA/ARS North Carolina State Univ. Raleigh, NC	Allen S. Heagle Virginia M. Lesser Joseph E. Miller
3.	Central States Regional Crop Loss Assessment Program (CSRCLAP)	Lance W. Kress Argonne National Lab Argonne, IL	Patricia M. Irving
4.	Southwest Regional Crop Loss Assessment Program (SWRCLAP)[d]/	O. Clifton Taylor University of California Riverside, CA	Patrick J. Temple
5.	Northwest Regional Crop Loss Assessment Program (NWRCLAP)	David T. Tingey Environ. Prot. Agency Corvallis, OR	Richard M. Adams David A. King Allen S. Lefohn Grady E. Neely

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[a]/ Program Statistician - John O. Rawlings, Professor of Statistics, Dept. of Statistics, N.C. State University, Raleigh, N.C.

[b]/ From 1981 to 1983 a site was operated in Beltsville, MD by USDA/ARS (Howard E. Heggestad and staff). In 1981 and 1982 a site was operated at Tracy, CA by Lawrence Livermore National Laboratory (Gail Bingham and staff).

[c]/ The Research Management Committee: Walter W. Heck (Chairman), O. C. Taylor (Assoc. Chairman), Richard M. Adams, Joseph E. Miller, David T. Tingey, Leonard H. Weinstein.

[d]/ The program has been conducted in Riverside, CA (1980), in Shafter, CA (1981, 1984), and in Tracy, CA (1981, 1982).

bean (dry), corn, cotton, forage (Ladino clover/fescue, red clover/timothy), grain sorghum, lettuce, peanut, soybean, tobacco, tomato and winter wheat. A few of these crops have been evaluated over two or more seasons, using one to several cultivars.

Table 1.2. summarizes the O_3 dose-response data which are currently available from NCLAN. Though the O_3 dose-response data base is now substantial, past research in NCLAN (Table 1.3.) and elsewhere has shown that genetic and environmental factors may affect plant response. Extrapolation of the site-specific dose-response data to estimate regional level yield changes introduces a number of uncertainties which cannot yet be quantified. Many cultivars of each crop species may be grown in a region. The NCLAN dose-response data address from one to several of them for each crop. Potential extrapolation errors are introduced because the quantitative response of cultivars within a species may be different. The degree of difference in relative sensitivity among cultivars can be estimated experimentally. Thus far, this has been done in the field only for corn and soybean. However, because dose-response curves have been developed for several cultivars of soybean and wheat at different experimental sites in different growing seasons, a preliminary evaluation of the significance of between-year and among-cultivar response differences can be conducted for these crops. Use of the Weibull function for modeling dose-response permits development of combination models which incorporate inherent variations in species response among sites, years, and cultivars.

A second significant source of extrapolative uncertainty results from insuffecent quantitative information describing how the O_3 dose-crop response may be affected by changes in plant water status. Experiments with alfalfa, barley, clover/fescue, cotton, and soybean have provided mixed results. The interaction of water stress with O_3 may be complex although it appears that sensitivity to O_3 is generally reduced under conditions of low soil moisture. Under conditions of moderate soil moisture stress and the presence of ambient O_3, some NCLAN results with soybean indicate that the effects of these two stresses on yield may be greater than additive. Substantial additional research will be required to fully define these relationships and employ them in NCLAN's economic assessments. Dose-response data for those crops that are not usually irrigated should be collected under several soil moisture regimes. These data would allow consideration of the potential impact of regional variations in soil moisture on the yield loss estimates. Accordingly, field and laboratory soil moisture studies are currently being conducted and will continue for the duration of the NCLAN program. This approach will allow the collection of appropriate data for the development of models to describe the effect of soil moisture on O_3 dose-response.

Other air pollutants may interact with O_3 to modify dose-response relationships, although the importance of these interactions to agriculture has not been fully elucidated. Experiments to date (Table 1.3.) suggest that these interactions may yield statistically significant results, but assessing their importance in affecting crop losses will require new techniques and additional experimentation.

Table 1.2. Crops and cultivars for which NCLAN has developed O_3 dose-response data[a]

Crop/cv.	% of Total Harvested Acreage	Crop Coverage Sites and Year Grown
Alfalfa	7	
WL-312		Argonne, IL (1984)
WL-514		Shafter, CA (1984)
Barley	3	
CM-72		Shafter, CA (1983)
Poco		Shafter, CA (1982)
Clover	3	
Ladino clover/Fescue		Raleigh, NC (1984)
Red clover/Timothy		Ithaca, NY (1984)
Corn	23	
PAG 397		Argonne, IL (1981)
Pioneer 3780		Argonne, IL (1981)
Cotton	3	
Acala SJ2		Shafter, CA (1981, 1982)
Stoneville 213		Raleigh, NC (1982)
Grain Sorghum	4	
A28+		Argonne, IL (1982)
Kidney bean	<1	
California Light Red		Ithaca, NY (1980, 1982)
Lettuce	<1	
Empire		Shafter, CA (1983)
Peanut	<1	
NC-6		Raleigh, NC (1980)
Soybean	20	
Davis		Raleigh, NC (1981, 1982, 1983, 1984)
Hodgson		Ithaca, NY (1981)
Williams - 79		Beltsville, MD (1981, 1982, 1983) Argonne, IL (1983)
Corsoy - 79		Argonne, IL (1980, 1983); Beltsville, MD (1983)
Essex		Beltsville, MD (1981)
Forrest		Beltsville, MD (1982)
Amsoy - 71		Argonne, IL (1983)
Pella		Argonne, IL (1983)
Tobacco	<1	
McNair 994		Raleigh, NC (1983)
Tomato	<1	
Jet Star		Beltsville, MD (1980)
Murietta		Tracy, CA (1981, 1982)
Wheat	22	
Abe		Argonne, IL (1982, 1983)
Arthur - 71		Argonne, IL (1982, 1983)
Roland		Argonne, IL (1982)
Vona		Ithaca, NY (1982, 1983)

[a] Source: USDA, Agricultural Statistics. 1984 (from the 1982 production year; kidney bean is value for all dry bean; clover and timothy are no longer determined - were about 3% in 1970.

Table 1.3. NCLAN field experiments related to interactions of genetic and environmental factors and O_3 dose-response

Crop/cultivar	Year	Site
Cultivar sensitivity ranking		
Corn (14 hybrids)	1981	Argonne, IL
Soybean		
Williams-79, Pella, Corsoy-79, Amsoy-71	1983	Argonne, IL
Interactions: O_3 and soil moisture		
Alfalfa, WL-514	1984	Shafter, CA
Barley, CM 72	1983	Shafter, CA
Cotton		
Acala SJ2	1981, 1982	Shafter, CA
Ladino Clover/Fescue	1984	Raleigh, NC
Soybean		
Williams-79, Forrest	1982	Beltsville, MD
Williams-79, Corsoy-79	1983	Beltsville, MD
Davis	1983, 1984	Raleigh, NC
Interactions: O_3 AND SO_2		
Alfalfa, WL-312	1984	Argonne, IL
Cotton		
Stoneville 213	1982	Raleigh, NC
Red Clover/Timothy	1984	Ithaca, NY
Soybean		
Davis	1981	Raleigh, NC
Williams-79	1981, 1982	Beltsville, MD
Essex	1981	Beltsville, MD
Forrest	1982	Beltsville, MD
Amsoy-71	1983	Argonne, IL
Corsoy-79	1983	Argonne, IL
Tomato		
Jet-star	1980	Beltsville, MD
Murrieto	1981, 1982	Tracy, CA
Wheat		
Vona	1983	Ithaca, NY
Ozone exposure dynamics		
Soybean		
Davis	1982	Raleigh, NC
Tobacco		
McNair 944	1983	Raleigh, NC

Two important assumptions must be made in applying the biological data to the national economic assessment. 1) All economically-important cultivars of species in aggregate respond similarly to those tested. 2) Environmental conditions differing from those in field experiments would not significantly affect the aggregate estimate of plant response to O_3. The validity of these assumptions is being tested and preliminary results are presented.

This report presents results from 1984 research. The results include the biological dose-response data for O_3 and data concerning modification of these responses by two environmental variables (soil moisture and SO_2). In addition, the efforts to develop a soil moisture/O_3 model and the application of these data to an evaluation of the economic consequences of O_3 air pollution for U.S. agriculture are discussed. We have stated rationale for and plans to develop a Data Synthesis and Extrapolation program and a review of the kriging method to extrapolate O_3 data into rural areas. This report includes a listing of all publications associated with the NCLAN program.

SECTION 2

CONCLUSIONS

We have not drawn conclusions from sections 5 and 6 because they are included to present plans and not results. Otherwise the conclusions address the most important results from each aspect of the NCLAN program.

Influence of Soil Moisture on Responses of Soybean to O_3 (Raleigh, NC)

Ozone and soil moisture stress decreased yield of Davis soybeans in open-top field chambers at Raleigh, NC. However, the level of soil moisture stress imposed did not significantly affect plant response to O_3; thus an O_3 by water stress interaction was not found. Regression models predicted a 13% loss in yield of Davis soybean at O_3 levels which occurred in Raleigh, NC in 1984.

Influence of Soil Moisture on Responses of a Ladino Clover/Fescue Mixture to O_3 (Raleigh, NC)

Ladino clover is much more sensitive to O_3 than is tall fescue. In a mixed stand, this resulted in a clover decline and a fescue increase. The rate of these changes increased as the O_3 concentration increased. Regression models indicate a 9% seasonal loss of the combined clover-fescue biomass at the O_3 concentration which occurred in Raleigh, NC during 1984. The moisture stress did not significantly alter the response of clover or fescue to O_3.

Response of Alfalfa to O_3 and Water Stress (Shafter, CA)

Ambient O_3 levels were comparatively low in Shafter in 1984, with only one hourly O_3 mean above 0.10 ppm. However, seasonal yields of normally irrigated and water-stressed alfalfa in non-filtered (NF) chambers were reduced 4.5% and 12.6%, respectively, compared with yields in the respective charcoal filtered (CF) chambers; showing a greater impact of O_3 on water-stressed plants.

Yield losses of normally irrigated alfalfa were inversely proportional to the square of the seasonal mean O_3 concentration; but in water stressed plots, yield losses were a linear function of seasonal mean O_3 concentrations.

Yield losses of water-stressed alfalfa were relatively greater than those of normally irrigated plants at low O_3 concentrations (near ambient), but water-stressed plants showed decreased sensitivity to O_3 at higher concentrations.

These results were related to the timing of ozone episodes in relation to irrigation events which influenced plant water status, stomatal conductance, and ozone flux.

Effects of O_3 and SO_2 on the Physiology and Yield of a Crop of Red Clover and Timothy (Ithaca, NY)

The evaluation of the effects of O_3 and SO_2 on the yield of a forage crop of red clover and timothy indicated that only O_3 reduced yield at the concentrations used. Exposure to SO_2 concentrations as high as 0.83 ppm (1-hr maximum) under dynamic conditions simulating pollutant regimes at a point source had no effect on yield and no pollutant interactions were found. Photosynthetic rates of red clover decreased with exposure to increasing concentrations of O_3; these reductions became more pronounced as the leaves aged. Oxygen evolution increased with leaf age and was greatest in those leaves receiving the highest O_3 treatment. Chlorophyll concentration and the ratio of chlorophyll a to b declined in the two highest O_3 treatment levels.

Impact of O_3 and SO_2 on Alfalfa (Argonne, IL)

There were no indications of either O_3 or SO_2 effects on the yield of alfalfa. Several factors (poor alfalfa site, drought, low O_3, leaf-rust infection, establishment year) other than O_3 tolerance may have contributed to the lack of air pollutant effects. There was only one harvest after treatments were initiated. There was, however, a positive correlation between O_3 concentration and both leaf chlorosis and saprophytic soil nematode populations. The same trend was noted between SO_2 concentration and nematode populations.

Quality Assurance for 1984 (Corvallis, OR)

All ozone, sulfur dioxide, and oxides of nitrogen analyzers performed satisfactorily or excellently in this year's performance audits. Accuracy weight checks indicated nearly all weight measurements were within 1% of the true weight. System evaluations indicated each location was in compliance with NCLAN quality assurance documentation requirements.

An Estimation of the Impact of Regional Moisture Stress on the O_3 Sensitivity of Soybean (Corvallis, OR)

Estimates of moisture stress impacts by Control Data Corporation (CDC) indicate a patchy distribution of drought for 1980. Moisture stress reduced soybean yields by 1 or more bushel per acre (rounded to the nearest bushel) in 46 of the 75 crop reporting districts modeled by CDC. At the state level, these predicted yield reductions ranged from 0 to 40%. Moisture stress effects on yield predicted by the O_3 x water stress model were highly correlated with CDC estimates, but not as great in magnitude as the latter. An assessment based on the combination of the results from CDC and the interaction model predicted a mean reduction in soybean yield sensitivity to O_3 of 20%, due to moisture stress, for 1980. However, this interaction is patchily distributed across the soybean producing areas and the interaction model has not been validated against field results.

Preliminary Assessment of the Economic Consequences of O_3 on U.S. Agriculture (Corvallis, OR)

The analysis and methodology associated with the 1984 preliminary NCLAN assessment are conceptually similar to the numerous induced change analyses found in the agricultural economic literature. The analysis is driven by NCLAN response data for six major crops (corn, soybeans, wheat, cotton, grain sorghum, and barley) which account for over 75 percent of U.S. cropped acreage. The economic model uses alternative O_3-induced yield changes from these NCLAN data to estimate the economic effects due to O_3 changes. The difference between a base solution reflecting 1980 parameters and hypothetical O_3 analyses provides an estimate of the benefits or costs of the O_3 change. The analysis indicates that the economic benefits to producers and consumers of agricultural commodities of a 25 percent O_3 reduction from 1980 ambient levels are approximately $1.7 to $1.9 billion. A similar increase in O_3 would result in damages of $2.1 to $2.4 billion. These economic effects are approximately 4-5 percent of the total farm value of the included crops. Effects on non-agricultural commodities as well as compliance costs of achieving any changes in ambient O_3 levels are not evaluated here, hence the estimates are not net economic effects.

SECTION 3

RECOMMENDATIONS

The results of NCLAN research suggest the need to better understand the influence of selected biotic and abiotic variables on the O_3 dose-response relationships for the crops studied. Factors considered important include soil moisture status, exposure dynamics, cultivar variability, other pollutants, insects and diseases. Assessment of the influence of these variables on O_3 dose-response functions will increase the accuracy of and confidence in the regional and national crop loss estimates and the economic assessments. To achieve these additions to our understanding of dose-response relationships and economic analyses, we identify the following priority research areas:

1) Development of O_3 dose-response relationships for hay crops should continue. After completing these hay crop studies, species accounting for approximately 95% of the U.S. agronomic crop acreage will have been evaluated in NCLAN.

2) It is important to understand the effects of soil moisture stress on yield response to O_3. These effects will be incorporated into dose-response functions and into a model that relates soil moisture stress to effects of O_3 on soybean. Both of these efforts will be used in economic loss assessments. The continued soil moisture stress studies should be conducted in the field using rainfall exclusion systems to allow more accurate control of soil moisture. The studies could start with two soil moisture levels but eventually at least three should be included. If three or more levels are considered they may be done by incorporating similar moisture stress treatments at different stages of plant growth. The energy status of the water in the primary root zone should be monitored.

3) The biological data synthesis and analysis program utilizing the NCLAN data base needs to be a continuing effort. This facilitates testing of new concepts and statistical models for predicting regional/national crop losses. Improved predictions can then be incorporated into the economic assessments. This program should also insure that a complete library of NCLAN data will be available for other scientists.

4) The scope of the national economic model should be expanded to accommodate a wide range of O_3-yield related issues. Alternative moisture stress scenarios and a less time-specific base model will increase the generality of the model for use in the 1987 assessment. Other issues, such as the effects of O_3 on yield variability, have important economic implications and should be tested and, if significant, incorporated in the economic model.

5) Additional refinements to the crop loss modeling effort should be explored. To the extent feasible, methodologies used in large area crop production forecasting should be incorporated into the models.

6) The exposure dynamics of the field experimental designs requires calibration as the NCLAN program moves from 7-h constant and proportional

O_3 additions to 12-h proportional additions. This is a critical component that will provide a melding of the constant and proportional types of data. The NCLAN program has compared the 7-h constant, 7-hr proportional and 12-h proportional using tobacco in 1983; a comparision of the 7-h constant and 7-h proportional was completed for soybean in 1982.

(7) The influence of various components of the O_3 exposure regime (e.g., concentration, exposure duration, and exposure frequency) on plant response should be evaluated to permit a better understanding of pollutant exposures and ways they relate to plant effects. Assessing exposure and dose characterizations and their relationships to yield losses will provide important information for setting secondary air quality standards. This research is supportive of that recommended in 6) above.

8) Cultivar screening to evaluate the degree of variability within a crop species should be initiated (several screens of a few cultivars for soybean and wheat are completed). These designs should assess the range of sensitivity within a species. Results should be used to develop a range of expected crop losses for each species tested. This could result in major changes in loss assessments.

9) Experiments to evaluate the effects of SO_2 exposure on O_3 dose-response functions should continue (through funding from the Electric Power Research Institute). Research is needed on the influence of NO_2 on plant growth and yield as NO_2 affects plant response to O_3 and SO_2.

10) Pollutant/pest interactions should be evaluated to assess the potential roles of air pollutants in altering disease epidemiology and insect population dynamics. Modification of insect and disease-induced crop losses by air pollutants could have a significant impact on national economic crop loss values.

11) Research on the effects of O_3 on yields of perennial crops such as grapes and apples and on the growth and marketability of ornamentals should be initiated. These crops are of considerable economic importance in their production areas and the regional consequences of pollutant-induced losses could be significant. Additionally, high value truck crops (i.e., bean, melon, potato) should be further studied.

The priority areas incorporated into the 1985 NCLAN research program include items 1 through 5 from the above listing. Although critical areas for crop assessment, the other areas will not be incorporated into the NCLAN program before the 1987 completion data for NCLAN.

Table 3.1. Summary of 1985 NCLAN field experiments.

Location	Design	Species Cultivars
Northeast		
Ithaca, NY	O_3- SO_2, Physiology and Yield	Red clover, Arlington/ Timothy, Champlain
Southeast		
Raleigh, NC	O_3 - Soil Moisture O_3 - Soil Moisture (Physiology and Yield on both)	Cotton Ladino clover, Regal/ Tall fescue, Kentucky 31
Central States		
Argonne, IL	O_3 - SO_2 O_3 - Soil Moisture	Corn, 4 hybrids Soybean, Corsoy-79
Southwest		
Shafter, CA	O_3 - Soil Moisture	Alfalfa, WL-514
Riverside, CA	O_3 - Soil Moisture	Cotton, SJ-2

SECTION 4

RESPONSE OF CROPS TO OZONE

4.1. SOIL MOISTURE/O_3 DOSE-RESPONSE RELATIONSHIPS

4.1.1. Influence of Soil Moisture on Responses of Soybean to O_3 (SERCLAP)--A. S. Heagle, R. B. Flagler, W. W. Heck, W. W. Cure V. M. Lesser, J. E. Miller, and Susan L. Corda

4.1.1.1. Objectives

1) Measure O_3 dose-yield relationships for soybeans grown with adequate and less than adequate soil moisture; 2) define growth curves, assimilate partitioning, and certain aspects of nitrogen and carbohydrate metabolism for plants exposed to the regimes outlined in objective 1; 3) obtain correlations between leaf area, shoot growth, canopy light reflectance and canopy light interception for plants exposed to the regimes outlined in objective 1.

4.1.1.2. Materials and Methods

Cultural. Seeds of soybeans *Glycine max* (L.) Merrill 'Davis' were planted in rows spaced 50 cm on 11 June in a 0.24-ha field of Norfolk loamy sand. Twenty-eight 3-m diameter plots were selected on 18 June based on plant stand and the physical appearance and depth of the topsoil. Plants were thinned to a stand of 19 plants per meter in each of three rows per plot on 29 June. Cultural practices were those commonly used for soybeans in the Southeast. A chronology of important activities in this experiment is shown in Table 4.1.1.1.

Pollutant treatment. The experimental design was two replicates (randomized blocks) of six chamber O_3 treatments [CF (charcoal filtered), NF (non-filtered), NF + 0.015, NF + 0.030, NF + 0.045, and NF + 0.060 ppm] and one nonchambered ambient air plot (AA) for each of two soil moisture levels. Constant amounts of O_3 were added to the NF + chambers for 7 hr/day (0900-1600 hr EST) from 7 July to 18 October except during rainy periods. Standard NCLAN protocols were used to monitor O_3.

Moisture treatments. For this study soil moisture status and plant water status were both determined on a regular basis. Soil-based measurements were determined using tensiometers and a neutron probe. Plant water status was determined using double-junction thermocouple psychrometers. The frequency of measurements varied with the type of measurement and the environmental conditions present in the field.

Tensiometers installed in each plot were used to monitor soil matric potential in the 0 to -0.07 MPa range. Location of each tensiometer was 0.5 m north of the center of the east row and 15 cm east of the row. Tensiometers were set at a depth of 20 cm. Each tensiometer was checked using a standard suction pump and gauge. Only tensiometers which agreed within ± 5% of the standard gauge were used. Tensiometers were read and checked daily (except during periods of rain).

Table 4.1.1.1. Chronology of activities during the experiment to determine the effects of soil moisture on soybean response to ozone at Raleigh, NC, 1984.

Month	Day	Event
May	21	Field sampled for fertilizer recommendation tests
June	11	Soybeans planted
		Fertilizer (0-0-60) applied (112 kg/ha)
		Treflan applied (2.3 l/ha)
	15	Plants emerged
	18	Plot locations chosen
	19	Chamber frames in place
	29	Preliminary harvest
July	2	Top and bottom panels installed
		Sevin 5D applied
		Irrometers installed
	7	Began dispensing O_3
	10	Second harvest
	25	Third harvest
August	1	Fourth harvest
	8	Fifth harvest
	9	Plictran applied (0.26 g/l)
	14	Orthene (3.9 cc/l) and Plictran (0.26 g/l) applied
	21	Plictran applied (0.26 g/l)
		Soil sampled from all plots for routine analysis
	22	Sixth harvest
	28	Plictran applied (0.26 g/l)
September	5	Seventh harvest
	6	Orthene applied (3.9 cc/l)
	18	Orthene applied (3.9 cc/l)
	19	Eighth harvest
	25	Orthene (3.9 cc/l) and Plictran (0.26 g/l) applied
October	2	Cygon 2E (3.9 cc/l) applied
	3	Ninth harvest
	10	Cygon 2E (3.9 cc/l) applied
	17	Tenth harvest
	18	Last day of dispensing O_3
	19	Bottom panels removed
	24	Eleventh harvest
November	6	Final harvest
	12	Soil samples taken from all treatment plots for analysis

The neutron probe was used for determining soil moisture content below the range in which tensiometers function. Access tubes for the neutron probe consisted of thin-wall aluminum irrigation pipe 5 cm in diameter. Access tubes were sealed at both ends with rubber stoppers to prevent the entry of moisture into the tube. One access tube was installed in each plot 0.5 m north of the center of the west row and 15 cm west of the row. Neutron probe measurements were taken at five depths (22.5, 30, 45, 60, and 75 cm). Frequency of neutron probe measurements varied with the field environment. Readings were made at least weekly in all plots on the same day.

Calibration of the neutron probe was done in the field where the study was conducted. Calibration consisted of taking measurements with the probe at various depths and taking soil samples at the same depth and location for gravimetric determination of soil moisture. This process was repeated over a range of soil moisture contents. Calibration equations for topsoil and subsoil were obtained. Each equation was based on 12 comparisons at different soil moisture levels. The models which describe the lines were all statistically significant.

Estimates of soil water potential were obtained from the neutron probe data by using soil moisture release curves for the field. Moisture release data were obtained by taking soil samples representative of the area to be measured, wetting the sample, and placing the sample in a pressure membrane apparatus. A range of pressures was applied to aliquots of the sample and moisture contents of the aliquots were determined gravimetrically after water outflow from the apparatus ceased. Moisture release equations for the topsoil and subsoil of the field used in this study were obtained. Each equation was based on 25 observations and each model was statistically significant.

Plant water status was determined using double-junction thermocouple psychrometers. All determinations of leaf water potential were made on the uppermost, fully expanded trifoliolate leaf. Determination consisted of placing a leaf sample in a brass cup which had a thin layer of silicon grease applied to it and clamping the sample cup to a brass psychrometer casing. The casings were transported to the laboratory in an insulated container and placed immediately into a constant temperature water bath at 26.0°C. A drop of double-distilled water was placed on one ring of each psychrometer and the psychrometers slipped into their respective casings. The tissue was allowed to reach equilibrium (approximately 4 h) and a series of voltage readings were taken at 15-min intervals with a microvolt meter. Equilibrium was defined as ≤ 0.05 V change in 15 min. Frequency of measurements varied with environmental conditions but were made at least biweekly. With one exception, measurements of leaf water potential were made on all plant harvest days. Due to limited availability of psychrometers and heavy demands on their use, only one replicate set of treatments was measured each time. Individual psychrometers were calibrated by taking microvolt readings from sample cups containing filter paper wetted with NaCl solutions of known water potentials which had reached equilibrium. A minimum of 21 points were used to establish a calibration for an individual psychrometer.

Plots selected to receive adequate irrigation were watered with drip tubing installed adjacent to each plot row when a tensiometer reading within either plot of a given O_3 level reached 0.03 MPa (30% of the tensiometer meter scale). Plots receiving less than adequate irrigation (stressed plots) were irrigated by O_3 treatment when neutron-probe readings at 22.5 cm indicated a reading corresponding to -0.50 MPa soil water potential within a given O_3 level. A total depth of 2.5 cm of water (190 liters) was applied (plot basis) for both plots of each moisture level-O_3 level combination at each irrigation.

Response measurements. Five plants were harvested from each plot starting on 10 July (second harvest) and continuing each 14 days for two harvests, each 7 days for two harvests, and then each 14 days for six harvests. Plants from weekly or biweekly harvests are used to establish growth curves for stems, roots, leaves, pods and seeds, to measure effects of drought and O_3 on nitrogen and carbohydrate metabolism, and to determine relationships between light interception by the canopy and leaf area and biomass. After the last biweekly harvest, two 1-m sections of row remained (in the NW and NE chamber quadrants) which contained nondisturbed plants. These plants were harvested for yield measures from all plots on 6 November.

Statistical Analyses. Analyses of variance of the plot data were performed on seed yield and seed number per 1-m row. These analyses were conducted over both moisture levels allowing a test for block, O_3, moisture, and O_3 by moisture interaction. In addition, an analysis of variance was performed for each moisture level to obtain O_3 effects and the residual mean square by moisture stress level. One CF moisture stress plot, located at the northernmost edge of this field, was eliminated from the analysis. Plants in this plot grew poorly from an unknown cause from the start of the season. Thus, all analyses are adjusted for an unbalanced data set.

Ozone dose-response curves were obtained for individual moisture levels and for the two moisture levels combined for soybean yield. Two classes of models were used to produce dose-response surfaces; polynomial dose response models and a nonlinear Weibull model. The polynomial response models allowed for the degree of polynomial necessary to fit the data. The Weibull and polynomial models, obtained over the two moisture stress levels, allowed an extra parameter to account for the effect of the moisture level.

4.1.1.3. Results

The 1984 season had record high rainfall (15.4 cm) during the first month of exposure (July), record low rainfall (2.1 cm) for August and very low rainfall (7.1 cm) for September and the first 17 days of October (Table 4.1.1.2). Thus, we were able to determine the effects of moisture stress on soybean response to O_3 during the critical stages of flowering and pod filling. Total irrigation amounts per plot are shown in Table 4.1.1.3.

The O_3 dispensing and monitoring systems worked well with total down-time due to malfunction and calibrations totalling 5% of the possible

Table 4.1.1.2. Dates, amounts, and pH of rainfall during the experiment to determine the effects of soil moisture on soybean response to O_3 at Raleigh, NC, 1984.

Date - 1984		Rainfall	
		cm [a]	pH
July	5	1.2	4.2
	6	1.6	4.4
	7	0.1	4.4
	13	3.3	4.1
	14	1.8	4.5
	16	0.1	4.4
	17	1.1	4.5
	18	1.2	4.3
	21	0.6	4.7
	22	0.1	4.5
	27	1.8	4.2
	28	0.5	4.2
	29	0.9	4.1
	31	1.1	4.9
August	1	0.1	5.3
	9	1.1	3.7
	10	0.5	4.2
	11	0.1	4.1
	31	0.3	4.4
September	10	0.1	5.4
	11	0.1	5.5
	13	3.3	5.0
	29	0.1	4.6
	30	2.6	4.6
October	1	0.8	3.9
	17	0.1	3.8
	Total	24.6	

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[a] Includes all rain events resulting in greater than .025 cm rain.

Table 4.1.1.3. Irrigation amounts per treatment in the soybean O_3-water stress study at Raleigh, NC in 1984.

Treatment[b]	Irrigation (cm) Per Treatment[a]	
	Adequate Soil Moisture	Less than Adequate Soil Moisture
CF	30.0	12.5
NF	32.5	12.5
NF + 0.015	22.5	12.5
NF + 0.030	30.0	12.5
NF + 0.045	22.5	12.5
NF + 0.060	20.0	10.0
AA	20.0	12.5

[a] Irrigation was applied in increments of 2.5 cm of water (whole plot basis) using drip tubes adjacent to each of three plot rows.

[b] CF = charcoal filtered chamber, NF = non-filtered chamber, AA = ambient air plot.

seasonal exposure time (Table 4.1.1.4). Seasonal O_3 concentrations per treatment are shown as seasonal 7-hr and 1-hr per day means and as highest and second highest 7-hr and 1-hr values (Table 4.1.1.5). Seasonal mean diurnal concentrations are shown for each O_3 addition treatment (7 hr) and for CF, NF, and AA (24 hr) in Table 4.1.1.6. Daily 7- and 24-hr mean O_3 concentrations in ambient air at Raleigh, NC from 7 July to 18 October are shown in Table 4.1.1.7. Moisture stress caused a mean seed yield loss of 22%. There was a general tendency for decreased yield with increased O_3 doses for both water regimes (Table 4.1.1.8). Unexpected values occurred for several of the treatments, most notably the NF treatment (both moisture levels), which were higher than those in the CF treatment, the 0.015 treatment (moisture stressed) and the 0.030 treatment (both moisture levels) (Table 4.1.1.8). We believe these were due to soil compaction in the east rows of some plots caused by the tractor used for planting.

The combined statistical analysis over both moisture stress levels for soybean yield indicated no effects of blocks, highly significant effects of O_3 and moisture treatments, but no O_3 by moisture interaction (Table 4.1.1.9). Seed number was significant for O_3 and moisture. The analysis of variance by moisture level showed a significant O_3 effect for adequate moisture (unstressed) plots but not for the inadequate moisture (stressed) plots (Table 4.1.1.9). The subsequent polynomial regression analyses for yield, however, showed a significant linear effect due to O_3 for both moisture treatments (Table 4.1.1.10). The significant linear effect of O_3 for the stressed plots is not a contradiction of the results from the analysis of variance; the test of the linear trend is a more powerful test. In this instance a linear response was significant and adequately fit the data for both moisture levels (Table 4.1.1.10). The Weibull models for the separate moisture analyses are presented in Table 4.1.1.11.

Polynomial regression analyses combining both moisture stress levels indicated a linear O_3 response and a moisture effect. A dummy variable (M) for moisture stress was used in these analyses, where M=0 indicates moisture stress and M=1 indicates no moisture stress. The Weibull model was also extended to include this moisture stress parameter. These models are both presented in Table 4.1.1.12. Predicted values for seed yield at different O_3 levels for unstressed and stressed treatments from polynomial and Weibull analyses are shown in Table 4.1.1.13.

Results for objectives 2 and 3 concerning growth rates, assimilate partitioning, metabolism, and relationships between growth rate and light interception are not presented. Results suggest that O_3 and water stress decrease levels of starch, soluble sugars, and nitrogen compounds in vegetative tissues.

Plans for 1985

The 1985 experiment will be similar to that in 1984 but with several changes: 1) we will test the effects of O_3 and soil moisture using Cotton, cv 'McNair 235'; 2) we will expose plants proportionally for 12 hr per day using two replicates of five chamber O_3 treatments; and 3) we will test a new rain exclusion system on two extra replicates of three of the five chamber O_3 treatments.

Table 4.1.1.4. Date and hours of suspended dispensing due to rain or system malfunction for O_3 in the soybean O_3 - water-stress study at Raleigh, NC in 1984.

Month	Day	Hours of Suspended Dispensing (due to rain)	Hours of Suspended[a] Dispensing (due to system malfunction)
July	6	1.0	0.5
	9		7.0
	10		7.0
	18	3.5	
	29	7.0	
	31	6.5	
August	7		7.0
	16		1.5
	27		1.0
September	6		5.0
	10	4.0	
	13	7.0	
	18		4.0
	25		3.0
	28	7.0	
October	9		1.0
	Totals	36.0	36.5
Seasonal percent of time[b]		4.9%	5.0%

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[a] All down-time that was not weather related is included in system malfunction (line calibration, monitor calibrations).

[b] 104 days x 7 hrs/day = 735 hours (July 7 - October 18).

Table 4.1.1.5. Seasonal O_3 concentrations for the experiment to measure effects of soil moisture on response of soybeans to O_3 at Raleigh, NC, 1984. [a]

	7-hr/day (0900-1600 hr EST) Values (ppm)			1-hr/day Values (ppm)		
Treatment	Seasonal Means	Highest Means	Second Highest	Seasonal Means	Highest Means	Second Highest
CF+	0.024	0.049	0.046	0.031	0.058	0.054
CF-	0.026	0.047	0.044	0.032	0.055	0.051
NF+	0.044	0.081	0.077	0.053	0.105	0.096
NF-	0.045	0.084	0.079	0.055	0.106	0.101
NF+0.015+	0.067	0.117	0.111	0.080	0.145	0.135
NF+0.015-	0.065	0.111	0.108	0.079	0.139	0.133
NF+0.030+	0.082	0.137	0.133	0.098	0.166	0.158
NF+0.030-	0.079	0.133	0.129	0.095	0.164	0.155
NF+0.045+	0.091	0.155	0.154	0.107	0.186	0.175
NF+0.045-	0.094	0.155	0.148	0.110	0.187	0.169
NF+0.06+	0.108	0.172	0.167	0.129	0.210	0.196
NF+0.06-	0.106	0.177	0.172	0.127	0.212	0.201
AA	0.051	0.089	0.088	0.060	0.113	0.108

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[a] All values are the mean of two sets of readings (2 plots) for the period from 7 July to 18 October. + = adequate soil water; - = less than adequate soil water.

Table 4.1.1.6. Mean diurnal fluctuations in O_3 concentrations for treatments in the experiment to measure effects of soil moisture on soybean response to O_3 at Raleigh, NC, 1984.

Scan Start	Seasonal Mean per Treatment per Hour of Day (ppm)[a]						
Time (EST)	AA	CF	NF	NF+.015	NF+.030	NF+.045	NF+.060
0850	0.035	0.017	0.029	0.035	0.047	0.069	0.077
0935	0.042	0.021	0.035	0.056	0.072	0.083	0.095
1020	0.047	0.023	0.041	0.063	0.078	0.088	0.102
1105	0.051	0.025	0.045	0.067	0.082	0.093	0.108
1150	0.054	0.027	0.047	0.070	0.085	0.096	0.111
1235	0.056	0.028	0.049	0.072	0.088	0.100	0.115
1320	0.056	0.028	0.050	0.074	0.088	0.099	0.113
1405	0.056	0.028	0.051	0.075	0.089	0.101	0.116
1450	0.056	0.027	0.050	0.074	0.090	0.103	0.118
1535	0.051	0.026	0.045				
1620	0.050	0.025	0.045				
1705	0.044	0.021	0.039				
1750	0.037	0.016	0.030				
1835	0.031	0.013	0.024				
1920	0.020	0.011	0.017				
2005	0.020	0.009	0.015				
2050	0.019	0.011	0.016				
2135	0.019	0.013	0.016				
2220	0.020	0.017	0.017				
2305	0.020	0.017	0.017				
2350	0.021	0.018	0.017				
0035	0.019	0.019	0.017				
0120	0.019	0.016	0.016				
0205	0.019	0.016	0.016				
0250	0.018	0.016	0.016				
0335	0.018	0.016	0.015				
0420	0.016	0.014	0.014				
0505	0.014	0.010	0.012				
0550	0.014	0.009	0.010				
0635	0.013	0.006	0.012				
0720	0.018	0.007	0.014				
0805	0.031	0.013	0.024				

[a] Each value is the mean for four plots (two plots for each of two soil moisture levels) for the period from 7 July to 18 October except for AA which is the mean of two values.

Table 4.1.1.7. Daily 7-and 24-hour mean O_3 concentration (ppm) in ambient air during the experiment to measure effects of soil moisture on soybean response to O_3 at Raleigh, NC 1984.

	July		August		September		October	
Date	7 hr[a]	24 hr	7 hr	24 hr	7 hr	24 hr	7 hr	24 hr
1			0.028	0.016	0.080	0.048	0.020	0.017
2			0.025	0.017	0.078	0.046	0.037	0.017
3			0.042	0.026	0.066	0.056	0.057	0.029
4			0.052	0.031	0.030	0.030	0.078	0.044
5			0.050	0.030	0.046	0.025	0.076	0.035
6			0.076	0.036	0.054	0.030	0.058	0.035
7	0.044	0.040	0.050	0.034	0.061	0.037	0.039	0.027
8	0.048	0.037	0.087	0.057	0.049	0.034	0.040	0.021
9	0.045	0.026	0.067	0.035	0.041	0.026	0.040	0.016
10	0.065	0.048	0.045	0.025	0.029	0.023	0.054	0.030
11	0.066	0.050	0.049	0.025	0.019	0.016	0.056	0.042
12	0.074	0.049	0.043	0.026	0.031	0.025	0.061	0.038
13	0.051	0.046	0.040	0.022	0.028	0.030	0.050	0.035
14	0.049	0.038	0.046	0.028	0.051	0.035	0.050	0.027
15	0.040	0.033	0.065	0.038	0.061	0.040	0.049	0.024
16	0.040	0.029	0.077	0.043	0.035	0.029	0.060	0.031
17	0.033	0.035	0.085	0.038	0.044	0.029	0.027	0.022
18	0.032	0.029	0.069	0.037	0.040	0.025	0.042	0.021
19	0.062	0.052	0.058	0.034	0.062	0.037		
20	0.029	0.020	0.054	0.033	0.079	0.045		
21	0.036	0.023	0.066	0.038	0.077	0.058		
22	0.024	0.021	0.088	0.044	0.064	0.059		
23	0.035	0.021	0.072	0.038	0.042	0.038		
24	0.046	0.029	0.059	0.040	0.048	0.038		
25	0.078	0.042	0.056	0.033	0.051	0.045		
26	0.059	0.037	0.066	0.034	0.064	0.052		
27	0.046	0.041	0.059	0.037	0.025	0.017		
28	0.038	0.034	0.064	0.050	0.009	0.008		
29	0.041	0.039	0.050	0.038	0.010	0.010		
30	0.038	0.032	0.056	0.037	0.037	0.023		
31	0.025	0.018	0.062	0.034				

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[a] Mean 7-hr/day concentrations from 0900 to 1600 hr EST. Each value is the mean for two monitors.

Table 4.1.1.8. Yield response of 'Davis' soybeans to chronic doses of O_3 when grown under water-stressed or adequate soil water conditions at Raleigh, NC 1984.[a]

	Adequate Moisture		Moisture Stressed[b]	
	Seed Wt. (g)/m	Seed Number per m of Row	Seed Wt. (g)/m	Seed Number per m of Row
CF	380	2157	297	1498
NF	433	2624	305	1718
NF+0.015	276	1648	309	1868
NF+0.030	319	2121	208	1187
NF+0.045	264	1651	222	1316
NF+0.060	232	1541	177	1077
AA	296	1772	234	1331

[a] Each value is the mean of four 1-m sections of row. Data reflect seed moisture content adjusted to 13%. Significance levels are shown in Table 4.1.1.9.

[b] One CF moisture stress plot was excluded. Since block effects were not significant the unadjusted mean is shown.

Table 4.1.1.9. Mean squares from analysis of variance for yield of soybeans exposed to O_3 and moisture stress at Raleigh, NC in 1984.[a]

Source	df	Yield[b] (hundreds)	Seed # (ones)
		Moisture Levels Combined	
Block	1	38	0.008
Ozone	6	116**	0.050*
Moisture	1	280**	0.147**
Ozone x Moisture	6	28	0.004
Error	12	15	0.013
		Adequate Moisture Plots - Separate	
Block	1	8	0.034
Ozone	6	99*	0.029
Error	6	15	0.017
		Inadequate Moisture Plots - Separate	
Block	1	36	0.0044
Ozone	6	49	0.0307*
Error	5	17	0.0052

[a] Analyses with one CF moisture stressed plot removed from data. Plot values are means of two quadrants per plot. Yield was measured in grams of seed per meter of row.

[b] * and ** significant at .05 and .01 probability levels, respectively.

Table 4.1.1.10. Polynomial regression equations for yield (g/m^2) of soybeans exposed to O_3, listed by moisture stress level in 1984.[a]

Unstressed

$$\begin{array}{lll} \text{Yield} = 466 & - & 2145x \\ \quad\quad\quad (30) & & (397) \end{array}$$

Stressed

$$\begin{array}{lll} \text{Yield} = 375 & - & 1744x \\ \quad\quad\quad (38) & & (495) \end{array}$$

---

[a] Analysis with one CF moisture stressed plot deleted from data. Standard errors for estimates given in parentheses. x = seasonal 7 hr per day mean O_3 concentration in ppm.

Table 4.1.1.11. Weibull regression equations for yield (g/m^2) of 'Davis' soybean exposed to O_3, listed by moisture stress level in 1984.[a]

Unstressed

$$Y = 412 \exp [- (x/0.136)^{2.17}]$$

(36, 0.018, 1.03)

Stressed

$$Y = 314 \exp [- (x/0.125)^{3.17}]$$

(26, 0.013, 1.55)

---

[a] Analysis with one CF moisture stressed plot deleted from data. Standard errors for parameters listed in order (α, σ, c); x = seasonal 7-hr per day mean O_3 concentration in ppm.

Table 4.1.1.12. Regression equations for yield (g/m^2) of 'Davis' soybean exposed to O_3, over moisture levels in 1984.[a]

Polynomial

$$y = \underset{(25)}{392} - \underset{(301)}{1984x} + \underset{(15)}{62M}$$

Weibull

$$y = (325 + 81M)\ \exp\left[- (x/0.132)^{2.45}\right]$$

$$(26,\ 20,\ 0.012,\ 0.90)$$

---

[a] Analysis with one CF moisture stressed plot deleted from data; x is the seasonal 7 hr per day mean O_3 concentration in ppm.

Standard errors for parameter estimates given in parenthesis; for Weibull model, in order: $(\alpha 1, \alpha 2, \sigma, c)$

M for both models is a dummy variable for moisture level; 0 = moisture stress, 1 = adequate moisture

Table 4.1.1.13. Predicted 1984 soybean yield values (g/m^2) from combined model (both moisture levels) for a range of O_3 values [a]

O_3 (ppm)	Polynomial		Weibull	
	+ Moist	- Moist	+ Moist	- Moist
.02	414	352	402	322
.025	404	342	399	320
.03	395	332	395	316
.04	375	313	385	308
.05	355	293	370	296
.06	335	273	351	281
.07	315	253	329	263
.08	295	233	303	242
.09	275	213	275	220
.10	256	194	245	196
.11	236	174	214	171

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[a] Equations shown in Table 4.1.1.12.

4.1.2. Influence of Soil Moisture on Responses of a Ladino Clover-Tall Fescue Mixture to O_3 (SERCLAP)--A.S. Heagle, Joanne Rebbeck, S.R. Shafer, Udo Blum, W.W. Heck, V.M. Lesser, J.E. Miller, and Diane Camberato

4.1.2.1. Introduction

Tall fescue (*Festuca arundinacea* Schreb.) and ladino clover (*Trifolium repens* L.) are commonly grown together in the southeastern United States. The clover in this mixture provides an economical source of nitrogen and protein for livestock but often disappears after a few years. Ozone is a possible cause for this lack of persistence. Soil moisture is one factor which may change the relationship between O_3 dose and yield response. Our objective was to measure the O_3 dose-yield relationships for a ladino clover-tall fescue mixture grown in the field at two soil moisture levels.

4.1.2.2. Materials and Methods

A mixture of ladino clover 'Regal' and tall fescue 'Kentucky 31' seeds were sown in a field of Appling soil on 15 September 1983. Fourteen 3-m diameter plots were chosen in each of two blocks on 2 April 1984 based on the uniformity of stand for both species (28 plots total). Six contiguous quadrats (36 cm x 51 cm each) were marked at the center of each plot on 18 April. Cultural practices were those commonly used for clover-fescue pastures in the Southeast. Herbicide and pesticide applications and the chronology for other important events are shown in Table 4.1.2.1. We applied Cygon after each harvest to prevent insect infestations.

The experimental design was two replicates (randomized complete blocks) of six O_3 levels in chambers and one nonchamber (AA) treatment for each of two soil moisture levels. The chamber O_3 treatments included charcoal filtered- air (CF), nonfiltered-air (NF), and four NF treatments to which O_3 was added to obtain amounts in the chambers proportional to the continuously monitored ambient O_3 concentration (NF x 1.25, NF x 1.50, NF x 1.75, and NF x 2.00 ppm). Ozone was added for 12 hr/day (0800 to 2000 hr EST) when the ambient O_3 concentration exceeded 0.03 ppm from 26 April to 18 October except during rainy weather and 1-day harvests. Standard NCLAN protocols were used to dispense and monitor O_3. Plants were irrigated through a rain-simulator nozzle mounted over the center of each plot at a height of 3 m. Irrigation of 2.5 cm of water was applied when the soil matric potential was -0.4 and -1.2 MPa (using a moisture release curve and gravimetric soil moisture measures) for the adequate and less than adequate moisture treatments, respectively.

Plants from each of the six quadrats were harvested by cutting to a height of 7-8 cm when they reached a height of approximately 25 cm. A frame was used to delineate each quadrat and to measure the cutting height. Plots were harvested before exposures began on 18 April (Block I) or 19 April (Block II) to provide baseline data for possible covariate analyses. During the exposure period, six additional harvests were performed starting on 15 May and ending on 23 October. As the season progressed, plants grew slower in the high than in the low O_3 treatments. Thus, plants in the higher O_3 treatments required more time to reach a height of 25 cm which

Table 4.1.2.1. Chronology of activities during the experiment to determine the effects of soil moisture on the response of clover-fescue to ozone at Raleigh, NC in 1984.

	Month	Day	Event
1983	September	15	Field planted with Ladino clover cv. Regal and tall fescue cv Kentucky 31
1984	April	2	Plots chosen; soil samples taken for nutrient analyses
		3	Chamber frames in place
		12	Permanent quadrats staked
		13	Root core samples taken outside the plots for carbohydrate analysis
		18	First harvest (Block I)
		19	First harvest (Block II)
		24	Top panels installed (Block I)
		25	Top panels installed (Block II); bottom panels installed, fans on
		26	Began dispensing O_3, 0800-2000 EST
	May	8	Malathion 5EC (7.8 cc/l) applied in plots and field
		14	Soil core samples taken for carbohydrate analysis
		15	Second harvest (Block I)
		16	Second harvest (Block II)
		17	Cygon 2-E (4.0 cc/l) applied to all plots
	June	5	Root core samples taken for carbohydrate analysis
		6	Third harvest (Block I)
		7	Third harvest (Block II)
		8	Cygon 2E (6.3 cc/l) applied to all plots
		14	Malathion 5EC (30 ml/gal) applied in field (not to plots)
		28	Fourth harvest (AA, NF, CF, NF x 1.25 treatment plots)
	July	2	Cygon 2E (6.3 cc/l) applied to all plots harvested on June 28
		9	Fourth harvest (NF x 1.50, NF x 1.75, NF x 2.00 treatment plots)
		11	Cygon 2E (6.3 cc/l) applied to all plots harvested July 9
		26	Root core samples taken for mycorrhiza and carbohydrate analysis
		27	Fifth harvest (AA, NF, CF, NF x 1.25 treatment plots)
	August	3	Cygon 2E (6.3 cc/l) applied to all plots harvested July 27
		9	Fifth harvest (NF x 1.50, NF x 1.75, NF x 2.00 treatment plots)
		10	Cygon 2E (6.3 cc/l) applied to all plots harvested August 1
		27	Soil samples taken to assay for rhizosphere fungi
		29	Sixth harvest (AA, NF, CF, NF x 1.25 treatment plots)

Table 4.1.2.1. Continued.

Month	Day	Event
September	4	Sixth harvest (NF x 1.50, NF x 1.75, NF x 2.00 treatment plots)
	17	Cygon 2E (6.3 cc/l) applied to all plots
	26	Root core samples taken for carbohydrates analysis
October	16	Cygon 2E (6.3 cc/l) applied to all plots
	18	Last day of dispensing O_3
	19	Seventh harvest (Block I), bottom panels removed
	22	Seventh harvest (Block II)
	26	Top panels removed, root core samples taken for mycorrhiza analysis
	29	Cygon 2E (6.3 cc/l) applied to all plots
November	5	Soil samples taken for soil nutrient analysis

resulted in different harvest dates depending on the O_3 treatment (Table 1). At each harvest, the shoots of clover, fescue and weeds were cut, hand separated, oven-dried and weighed.

Analyses of variance were performed for the moisture levels combined and by individual moisture level for cumulative clover dry weight, cumulative fescue dry weight, and cumulative total forage dry weight (total forage dry weight = clover + fescue weight). These weights are cumulative weights summed over the six harvests. For the individual moisture level analyses, the significance of blocks and O_3 was determined, while the analysis for moisture levels combined determined the significance of block, O_3, moisture, and O_3 by moisture interaction.

Pollutant dose-response models were fit for the total forage weight. Polynomial dose response models and nonlinear Weibull models were obtained for the combined (adequate plus inadequate moisture plots) and separate analyses. The response models fit for the combined moisture levels allowed for an added parameter to account for the moisture effect.

The 1984 seasonal rainfall patterns were unusual with 21, 12, 15, 2, and 6 cm of rain for the months of May, June, July, August, and September, respectively (Table 4.1.2.2). Only 12 cm of rain fell from 1 August to 18 October. Thus, we were able to establish different levels of soil moisture through differential irrigation for part of June, all of August, the first 12 days of September and between 2 and 18 October (Table 4.1.2.3).

4.1.2.3. Results

Pollutant doses. Dates and hours of suspended O_3 dispensing due to system malfunctions, harvests, rain, and irrigation are shown in Table 4.1.2.4. Total dispensing down time due to all of these causes was 10.3%. The mean seasonal 12 hr (0800 to 2000 hr EST) O_3 concentrations in ambient air during the exposure period (26 April to 18 October) was 0.052 ppm (Table 4.1.2.5).

The mean seasonal O_3 concentrations for the chamber O_3 treatments are shown in Table 4.1.2.5. These data show that we were within 10% of our target dispensing proportions for all treatments.

The mean seasonal diurnal fluctuation in O_3 concentrations for ambient air and for the chamber treatments are shown in Table 4.1.2.6. Daily 12 (0800-2000 hr EST) and 24 hr O_3 concentrations in ambient air from 26 April to 18 October are shown in Table 4.1.2.7.

Yield. In the moisture stressed plots, cumulative yield of clover and fescue was 10 and 8% less, respectively, than that in adequate moisture plots (Table 4.1.2.8). The effect of O_3 was to decrease yield of clover and to increase yield of fescue in both moisture treatments. Apparently, the decreased yield of clover, which appeared to be more sensitive than fescue to O_3, resulted in less competition for fescue.

Analyses of variance combined over moisture levels for clover, fescue, and total forage weight showed significant effects due to O_3. Clover and total forage weights also showed significant effects of moisture and block.

Table 4.1.2.2. Dates, amounts, and pH of rainfall during the experiment to determine the effects of soil moisture on response of clover-fescue to O_3 at to O_3 at Raleigh, NC in 1984.

Date - 1984		Rainfall	
		cm[a]	pH
April	30	0.4	4.3
May	1	0.4	4.4
	2	0.2	4.2
	7	0.3	4.8
	8	1.7	4.5
	23	1.3	4.6
	27	5.0	4.8
	28	8.2	5.0
	29	1.6	4.3
	30	1.7	4.4
June	16	0.1	4.3
	17	1.0	4.4
	20	2.3	4.0
	23	0.4	4.3
	28	4.7	4.4
	29	1.4	4.5
	30	1.9	4.4
July	5	1.2	4.2
	6	1.6	4.4
	7	0.1	4.4
	13	3.3	4.1
	14	1.8	4.5
	16	0.1	4.4
	17	1.1	4.5
	18	1.2	4.3
	21	0.6	4.7
	22	0.1	4.5
	27	1.8	4.2
	28	0.5	4.2
	29	0.9	4.1
	31	1.1	4.9
August	1	0.1	5.3
	9	1.1	3.7
	10	0.5	4.2
	11	0.1	4.1
	31	0.3	4.4
September	10	0.1	5.4
	11	0.1	5.5
	13	3.3	5.0
	29	0.1	4.6
	30	2.6	4.6
October	1	3.8	3.9
	17	0.1	3.8
	Total	60.2	

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[a] Includes all rain events resulting in depth greater than .025 cm.

Table 4.1.2.3. Dates of irrigation in the clover-fescue O_3-water-stress study at Raleigh, NC in 1984.

		Soil Moisture Treatment[a]	
Dates Irrigated		Adequate	Inadequate
May	19	x	x
	22	x	x
June	13	x	
	18	x	x
August	16	x	
	20	x	x
	28	x	
	31	x	x
September	4	x	
	14	x	x
	24	x	
October	12	x	
	15		x
	24	x	x
	Total	30 cm	20 cm

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[a] Irrigation (2.5 cm) was applied when adequately watered plots reached a soil matric potential of approximately -0.4 MPa and inadequately watered plots reached approximately -1.2 MPa, as determined gravimetrically. Water was applied by overhead irrigation. The flow rate of nozzle was measured to determine irrigation duration for each plot.

Table 4.1.2.4. Dates and hours of suspended dispensing due to system malfunction, harvest, ambient rain, and irrigation for the clover-fescue O_3-water-stress study at Raleigh, NC in 1984.

		Hours of Suspended Dispensing Due to:			
Month	Day	System Malfunction	Harvest	Rain	Irrigation
May	15		12.0		
	16		12.0		
	17	12.0			
	19				2.5
	22				2.0
	30			12.0	
June	6		12.0		
	7		12.0		
	8	2.0			
	16	0.5			
	18				2.0
	28		12.0		
July	9		12.0		
	11	2.0			
	18	5.0			
	19	9.0			
	20	2.0			
	27		12.0		
	30	1.5			
August	4	12.0			
	9		12.0		
	16				1.5
	20				3.5
	27	1.0			
	28				3.5
	29		12.0		
	31				3.0
September	4				3.5
	7		12.0		
	14				2.5
	24				3.5
October	5	0.5			
	9	1.0			
	12				3.0
	15				3.0
Total hours		49.5	120.0	12.0	33.5
Seasonal percent of time down[a]		2.4	5.7	0.6	1.6

[a] Seasonal total calculated as 175 days x 12 hours = (2100 hours) from April 26 to October 17.

Table 4.1.2.5. Seasonal O_3 concentrations for the experiment to measure the effects of soil moisture on response of clover-fescue to O_3 at Raleigh, NC in 1984.[a]

	12-hr/day Values (ppm)			1-hr/day Values (ppm)		
Treatment	Seasonal Means	Highest	Second Highest	Seasonal Means	Highest	Second Highest
*CF+	.025	.048	.044	.037	.073	.057
*CF-	.025	.049	.042	.038	.070	.067
*NF+	.043	.094	.089	.058	.126	.105
*NF-	.045	.096	.080	.060	.119	.117
NFx1.25+	.062	.138	.123	.088	.191	.178
NFx1.25-	.061	.130	.117	.085	.176	.166
NFx1.50+	.071	.154	.137	.100	.207	.201
NFx1.50-	.070	.159	.142	.099	.196	.191
NFx1.75+	.079	.186	.155	.114	.245	.227
NFx1.75-	.079	.182	.159	.115	.233	.226
NFx2.00+	.088	.201	.180	.128	.264	.254
NFx2.00-	.088	.208	.189	.129	.255	.252
AA (roof)	.052	.096	.084	.066	.128	.118
*AA+(field)	.045	.086	.085	.061	.125	.115
*AA-(field)	.045	.088	.083	.063	.118	.112

[a] Each value is the mean of two sets of readings, except those marked with an asterisk which are a single value; + = adequate soil water; - = water-stressed.

Table 4.1.2.6. Mean seasonal diurnal fluctuations in O_3 concentrations for various treatments in the experiment to measure effects of soil moisture on response of clover-fescue to O_3 at Raleigh, NC in 1984.

Scan Start	Seasonal Mean per Treatment per Hour of Day (ppm)[a]						
Time (EST)	AA	CF*	NF*	NFx1.25	NFx1.50	NFx1.75	NFx2.00
0815	0.030	0.016	0.027	0.029	0.030	0.033	0.033
0900	0.037	0.020	0.033	0.041	0.045	0.050	0.053
0945	0.043	0.024	0.039	0.050	0.057	0.063	0.070
1030	0.049	0.026	0.043	0.058	0.066	0.075	0.082
1115	0.052	0.028	0.047	0.064	0.074	0.083	0.091
1200	0.054	0.029	0.049	0.069	0.078	0.089	0.098
1245	0.057	0.030	0.051	0.072	0.082	0.093	0.103
1330	0.057	0.031	0.052	0.073	0.083	0.094	0.105
1415	0.058	0.032	0.053	0.076	0.086	0.097	0.108
1500	0.058	0.031	0.053	0.076	0.087	0.099	0.108
1545	0.057	0.029	0.053	0.078	0.089	0.101	0.111
1630	0.056	0.029	0.052	0.077	0.088	0.100	0.111
1715	0.052	0.024	0.048	0.074	0.085	0.098	0.107
1800	0.044	0.020	0.041	0.063	0.072	0.083	0.091
1845	0.035	0.015	0.031	0.050	0.057	0.064	0.073
1930	0.029	0.012	0.023	0.039	0.046	0.054	0.057
2015	0.028	0.014	0.020				
2100	0.027	0.017	0.020				
2145	0.028	0.020	0.021				
2230	0.027	0.020	0.021				
2315	0.027	0.020	0.021				
2400	0.026	0.020	0.020				
0045	0.026	0.020	0.020				
0130	0.025	0.020	0.020				
0215	0.025	0.020	0.019				
0300	0.024	0.018	0.018				
0345	0.022	0.018	0.018				
0430	0.021	0.013	0.016				
0515	0.018	0.009	0.014				
0600	0.019	0.009	0.014				
0645	0.020	0.010	0.016				
0730	0.024	0.011	0.018				

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[a] Each value is the mean for two monitors (plots) for each of two soil moisture levels (except for those marked with an asterisk which are the mean for one monitor for each soil moisture level) for the period 26 April to 17 October.

Table 4.1.2.7. Daily 12 and 24 hour mean O_3 concentrations (ppm) in ambient air during the experiment to measure effects of soil moisture on response of clover-fescue to O_3 at Raleigh, NC in 1984.

	April		May		June		July		August		September		October	
Date	12 hr[a]	24 hr	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr
1			0.050	0.039	0.060	0.046	0.055	0.041	0.022	0.015	0.079	0.052	0.018	0.016
2			0.019	0.018	0.075	0.061	0.049	0.039	0.023	0.017	0.078	0.050	0.032	0.019
3			0.037	0.034	0.076	0.060	0.053	0.035	0.039	0.027	0.069	0.065	0.050	0.032
4			0.048	0.042	0.071	0.056	0.050	0.040	0.046	0.030	0.032	0.035	0.077	0.050
5			0.048	0.040	0.073	0.055	0.043	0.037	0.045	0.030	0.045	0.028	0.067	0.041
6			0.027	0.027	0.068	0.054	0.030	0.027	0.061	0.035	0.054	0.035	0.054	0.038
7			0.031	0.027	0.061	0.050	0.044	0.033	0.058	0.042	0.051	0.039	0.031	0.030
8			0.034	0.033	0.062	0.056	0.047	0.040	0.079	0.064	0.046	0.038	0.034	0.022
9			0.040	0.035	0.055	0.050	0.042	0.028	0.061	0.041	0.037	0.029	0.032	0.017
10			0.042	0.029	0.056	0.044	0.068	0.056	0.042	0.032	0.027	0.023	0.044	0.030
11			0.064	0.047	0.050	0.037	0.067	0.055	0.047	0.037	0.013	0.015	0.049	0.045
12			0.061	0.053	0.053	0.047	0.063	0.048	0.047	0.030	0.026	0.024	0.050	0.039
13			0.058	0.052	0.048	0.037	0.049	0.046	0.038	0.027	0.027	0.028	0.041	0.034
14			0.055	0.047	0.041	0.035	0.050	0.041	0.048	0.036	0.047	0.036	0.039	0.026
15			0.046	0.042	0.092	0.065	0.038	0.033	0.069	0.045	0.055	0.042	0.037	0.023
16			0.036	0.028	0.064	0.060	0 036	0.029	0.080	0.041	0.035	0.030	0.046	0.030
17			0.044	0.031	0.038	0.037	0.033	0.036	0.069	0.039	0.041	0.031	0.020	0.020
18			0.065	0.042	0.066	0.047	0.035	0.032	0.064	0.040	0.036	0.029	0.031	0.019
19			0.077	0.067	0.064	0.045	0.057	0.049	0.055	0.040	0.054	0.040		
20			0.076	0.069	0.056	0.034	0.026	0.021	0.051	0.036	0.075	0.050		
21			0.060	0.052	0.055	0.037	0.032	0.024	0.060	0.044	0.075	0.057		
22			0.050	0.040	0.075	0.056	0.021	0.021	0.080	0.049	0.069	0.052		
23			0.025	0.026	0.052	0.042	0.027	0.021	0.060	0.040	0.032	0.021		
24			0.058	0.038	0.035	0.024	0.037	0.027	0.056	0.044	0.042	0.029		
25			0.059	0.037	0.066	0.038	0.064	0.041	0.052	0.038	0.047	0.031		
26	0.077	0.073	0.056	0.044	0.068	0.044	0.050	0.037	0.063	0.040	0.057	0.046		
27	0.062	0.051	0.025	0.022	0.079	0.056	0.046	0.042	0.060	0.040	0.021	0.021		
28	0.041	0.031	0.027	0.024	0.042	0.034	0.040	0.037	0.065	0.053	0.010	0.009		
29	0.044	0.031	0.028	0.028	0.044	0.038	0.042	0.040	0.046	0.039	0.012	0.011		
30	0.039	0.037	0.020	0.020	0.048	0.037	0.037	0.033	0.056	0.041	0.029	0.025		
31			0.037	0.026			0.021	0.019	0.059	0.036				

[a] Mean concentrations from 0800-2000 hr EST. Each value is the mean for two monitors.

Table 4.1.2.8. Total cumulative yield of ladino clover and tall fescue grown in a mixture at two levels of soil moisture and exposed to different levels of O_3 for 12 hr/day from 26 April to 18 October at Raleigh, NC in 1984.

	Cumulative Clover Dry wt-g/Quadrat		Cumulative Fescue Dry wt-g/Quadrat		Cumulative Total Dry wt-g/Quadrat	
	Adequate Moisture	Inadequate Moisture	Adequate Moisture	Inadequate Moisture	Adequate Moisture	Inadequate Moisture
CF	187	156	15	27	201	183
NF	167	150	34	27	201	177
NF x 1.25	137	124	36	35	173	159
NF x 1.50	107	97	63	57	170	154
NF x 1.75	96	89	67	57	163	146
NF x 2.00	84	64	78	61	162	125
AA	161	162	18	18	179	180
Totals	938	842	311	282	1249	1124

[a] Each value is the mean of 12 quadrats (6 quadrats in each of two plots (blocks). Cumulative yield is the total from 6 harvests over the season. To convert g/quadrat to g/m^2, divide by 0.18. Significance levels are shown in Table 4.1.2.9. and 4.1.2.10.

For all variables, there was no O_3 by moisture interaction detected (Table 4.1.2.9). Partitioning the analysis by moisture level showed highly significant O_3 effects for all yield variables for both stressed and unstressed plots (Table 4.1.2.10).

Regression analyses were performed for total forage weight. Polynomial regression analyses over the moisture stress levels indicated that a linear O_3 response and a moisture effect variable adequately fit the data. The moisture effect variable, a dummy variable (M), was created where M=0 indicates moisture stress and M=1 indicates no moisture stress. The Weibull model was also extended to include this moisture stress parameter (Table 4.1.2.11). Polynomial and Weibull regression equations were also obtained for each moisture stress level and are shown in Table 4.1.2.12. For the polynomial models, a linear response for both moisture stress levels was found to adequately fit the data. Predicted yield (clover + fescue) values from combined polynomial and Weibull models at different levels of O_3 at each moisture level are shown in Table 4.1.2.13.

Summary

One of the most important forage crops in the southern United States is a mixture of ladino clover and tall fescue. However, this crop routinely suffers from a decline in clover production after the first year of growth which decreases quality of the forage. NCLAN results from Raleigh, NC indicate that O_3 could contribute to this decline. A field-grown mixture of ladino clover and tall fescue was exposed to chronic doses of O_3 in open-top field chambers which allowed control of O_3 concentrations throughout the season. Regression models indicated a 9% yield loss of the forage mixture at ambient levels of O_3 found near Raleigh, NC. The O_3 effects were similar at two levels of soil moisture (well-watered and moderately stressed). Clover showed extensive injury at ambient levels of O_3 and was much more sensitive than the fescue which showed injury only at the highest O_3 levels. However, at low doses of O_3, there was still a greater yield of clover than of fescue. At the highest dose of O_3 fescue yield was similar to yield of clover, probably because of O_3-induced growth decline of clover which decreased competition and allowed the more resistant fescue to grow more rapidly. This study is continuing for a second year using the same treatment plots.

Table 4.1.2.9. Mean squares from analyses of variance for yield for clover and fescue exposed to O_3 and moisture stress at Raleigh, NC in 1984.[a], [b], [c]

Source	df	Clover	Fescue	Total Forage[d]
Block	1	915**	12	720**
Ozone	6	5875**	1788**	2989**
Moisture	1	1320**	126	2261**
Ozone * Moisture	6	102	78	125
Error	13	61	94	77

[a] Yields are cumulative dry weights over 6 harvests during 1984.

[b] Plot values are means of six quadrants per plot.

[c] * and ** = significant at .05 and .01 probability levels, respectively.

[d] Total forage = clover + fescue dry weights.

Table 4.1.2.10. Mean squares from analysis of variance for yield of clover and fescue exposed to O_3, listed by moisture stress level, at Raleigh, NC in 1984.[a],[b],[c]

		Inadequate Moisture		
Source	df	Clover	Fescue	Total Forage
Block	1	990*	9	813*
Ozone	6	2879**	637**	1817**
Error	6	73	112	60

		Adequate Moisture		
Source	df	Clover	Fescue	Total Forage
Block	1	128	4	89
Ozone	6	3097**	1230**	1297**
Error	6	26	92	77

[a] Yields are cumulative dry weight (grams per 36 x 51 cm quadrat) over 6 harvests during 1984. Total forage = clover + fescue dry weight.

[b] Plot values are means of six quadrats per plot.

[c] * and ** significant at .05 and .01 probability levels, respectively.

Table 4.1.2.11. Regression equations for total weight (g/quadrat) of clover-fescue exposed to O_3 and moisture stress at Raleigh, NC in 1984.[a],[b]

Polynomial

$$\underset{(5.7)}{y = 241.3} - \underset{(84)}{1184x} + \underset{(3.3)}{17.8\,M}$$

Weibull

$$y = (206.4 + 24.9M)\ \exp\left[-(x/0.1215)^{2.51}\right]$$
$$(6.9,\ 4.7,\ 0.0086,\ 0.55)$$

---

[a] Standard errors given in parenthesis below equation. For Weibull, they are listed in order: $(\alpha 1,\ \alpha 2,\ \sigma,\ c)$

[b] For moisture level, a dummy variable was coded as:

$M = 0$ moisture stress
$M = 1$ moisture unstressed

$x = O_3$ concentration (seasonal 12 hr per day mean) in ppm.

Table 4.1.2.12. Polynomial and Weibull regression equations by moisture level for total yield of clover-fescue forage exposed to O_3 at Raleigh, NC 1984.[a]

Polynomial Models	Weibull Models
Adequate moisture	Adequate moisture
$y = 256.4 - 1115x$ (7.6) (117)	$y = 233 \exp[-(x/0.137)^{2.02}]$ (13, 0.020, 0.76)
Inadequate moisture	Inadequate moisture
$y = 244.1 - 1254x$ (6.9) (107)	$y = 205.9 \exp[-(x/0.1093)^{3.15}]$ (6.9, 0.0064, 0.73)

---

[a] Standard errors for estimates given in parenthesis in order: (α, σ, c); x = O_3 concentration (seasonal 12 hr per day mean) in ppm; values in g/quadrat.

Table 4.1.2.13. Predicted total clover-fescue weight from combined models for plants exposed to O_3 at Raleigh, NC in 1984.[a]

Seasonal mean 12 hr/day O_3 conc. (ppm)	Polynomial		Weibull	
	Adequate Moisture	Inadequate Moisture	Adequate Moisture	Inadequate Moisture
.02	235	218	229	204
.025	230	212	227	202
.03	224	206	224	200
.04	212	194	217	194
.05	200	182	207	185
.06	188	170	195	174
.07	176	158	180	160
.08	164	147	162	145
.09	153	135	144	128
.10	141	123	124	111

[a] Values shown are grams dry weight per quadrat (36 x 51 cm). To convert g/quadrat to g/m^2 divide by 0.18.

4.1.3. Responses of Alfalfa to O_3 and Water Stress (SWCLAP)--P.J. Temple, O. C. Taylor, L. F. Benoit, C. A. Reagan, R. W. Lennox

4.1.3.1. Objectives

Alfalfa (Medicago sativa L) hay is one of the ten most valuable crops grown in the U.S. and the third most economically important crop in California (9). Most of the alfalfa hay produced in California is grown in the southern and central San Joaquin Valley, an agricultural area in which previous field studies showed that ambient levels of O_3 reduced growth and yield of some crops (10). Alfalfa is known to be susceptible both to visible injury and to growth reductions induced by O_3 (11,12).

Alfalfa is grown under irrigation throughout the arid western U.S. Because crop response to O_3 can be highly dependent upon plant water status, the amount and timing of irrigation events can be important in determining crop yield losses to O_3. The objectives of this research were: 1) to establish crop loss-O_3 dose response equations for field-grown alfalfa for use in national assessments of economic impacts of air pollution on U.S. agriculture; 2) to determine how plant water status altered or modified these dose-response functions; 3) to explore the physiological bases for the effects of plant water status on O_3 response.

4.1.3.2. Materials and methods

Ozone treatments. Alfalfa plots were established in August 1983 on the same field site used in previous NCLAN experiments in Shafter. A cow pea (Vigna sinensis L) cover crop was incorporated to a depth of 30 cm. and superphosphate fertilizer (0-25-0-10S) was spread over the area at a rate of 140 kg P ha^{-1}. The field was treated with Balan (pre-emergence herbicide) at a rate of 7 L ha^{-1}. Alfalfa seed (cv. 'WL-514', non-winter dormant), precoated with Rhizobium meliloti Dan. was spread at a rate of 22.4 kg ha^{-1}. The alfalfa stand was maintained on sprinkle-irrigation until the plants were well established. On 15 March 1984, open-top chambers were centered on a 1 m^2 sample area in the center of each 3 m x 5.5 m plot. Ozone treatments were randomly distributed among 30 plots as follows: 6 each of ambient air (AA), charcoal-filtered (CF) and non-filtered (NF); 4 each of NF x 1.3, NF x 1.7, and NF x 2.0. Ozone was added by proportional controller; additions began at or after 0900 when ambient O_3 exceeded 0.03 ppm. Ozone addition shut off automatically when ambient O_3 fell below 0.03 ppm or at 2100, whichever came first. Ozone addition began on 16 March 1984 and continued daily until harvest day; O_3 additions began 2 d after each harvest. Ozone dispensing, monitoring, and data acquisition systems were the same as those used in previous NCLAN experiments. All NCLAN quality assurance protocols regarding instrument calibration and line loss checks were made at prescribed intervals. Line losses did not exceed 5 percent. Meteorological data were obtained from a USDA meteorological station located 300 m northeast of the field plots.

Irrigation treatments. Ozone treatments were divided at random into equal numbers of normally irrigated (NI) and water-stressed (WS) treatments. Irrometers were placed at depths of 45 cm and 60 cm in each plot. Access tubes 1.2 m long for neutron probe readings were placed near the center of each plot. Neutron probe readings were taken weekly between 0700 - 1000 with a Troxler Model 3220 depth moisture gauge (Troxler Electronic Labs, Sacramento, CA) at depths of 23 cm, 46 cm, and 91 cm. The NI plots were watered by furrow irrigation when the mean soil moisture level at 23 cm reached 3.3 cm (50% depletion of available soil moisture at field capacity). Plots were irrigated to field capacity to a depth of 1 m. The WS plots were irrigated when soil moisture at 23 cm depth fell below 2.5 cm (75 % depletion of available soil moisture) and when plant water status measurements indicated that the plants were under water stress. The WS plots were irrigated to 75% of field capacity at 1 m depth. Plant water status was determined by pressure bomb (Plant Water Status Console, Model 3000, Soil Moisture, Inc., Santa Barbara, CA). Readings were taken at solar noon on 2 or 3 stems adjacent to the sample area in each plot. Readings of -1.2 MPa or lower were considered as evidence of plant water stress (13,14). An infra-red heat gun (Everest Interscience, Model 110, Tustin, CA) was used to determine ambient air and canopy temperature differentials. These readings were taken at solar noon once the canopy reached 100% cover. Reading angle (45°) and area of scan (center of sample area) were standardized to permit comparison of data from plot to plot and from day to day. Canopy temperatures greater than ambient temperatures were considered evidence of plant water stress (14-16).

Diurnal curves of stomatal conductance and transpiration were measured periodically with a steady-state porometer (LI-COR Model 1600; Li-COR Corp, Lincoln, NB). On 19 July, measurements were taken hourly from 0600 to 2000 on abaxial and adaxial surfaces of terminal leaflets of five fully expanded leaves in each NI treatment. Photosynthetic rates were measured from 1100 to 1400 by uptake of $^{14}CO_2$ from abaxial leaf surfaces following the method of Johnson et al. (17). Measurements were made on five plants in two replicate chambers for each treatment. Stomatal density of alfalfa is approximately 20% greater on abaxial than on adaxial leaf surfaces (18).

Disease and pest control was minimal. Thuricide (Bacillus thuringensis) at 583 ml ha^{-1} was used at 5-day intervals during August and September to control lepidopteran larvae.

Harvest procedures. Timing of harvests was based on elongation of crown resprouts (1 to 2 cm) and flower bud development (1/10 bloom stage). Harvest intervals ranged from 3-5 weeks over the O_3 dispensing season. The single m^2 sample area was divided into four, 0.25 m^2 quadrants which were cut individually at a height of 5 cm with electric hedge trimmers. Fresh weights were taken immediately after cutting; the samples were dried at 55°C until no weight change was detected and the oven dry weights were determined immediately after removal from the dryer. All NCLAN quality assurance protocols regarding processing of biological samples were observed during harvest, weighing, and data collection. Samples from the first harvest in April and from the fourth through seventh harvest were ground and analyzed for protein using an infrared autoanalyzer (Technicon InfraAlyzer 400; Technicon Corp., Tarrytown, N.Y.) at the UC Agricultural Research and Extension Station, Parlier, CA.

Data Analysis. The experiment was designed as a completely randomized experiment with unequal replication. Individual quadrat harvest data from each plot were summed to produce plot yields in terms of gm^{-2}. Plot yields from the seven harvests during the period of O_3 addition were summed to produce total seasonal harvests for each plot. These data were analysed by analysis of variance and by regression analysis using polynomial and Weibull models.

4.1.3.3. Results

Air quality and meteorology. Growing conditions during most of 1984 were near normal for the San Joaquin Valley except for July - September, which were drier than normal. Pan evaporation averaged 13% - 18% higher than the mean of the previous eight years during this period (Table 4.1.3.1.). Ambient O_3 concentrations were relatively low in Shafter in 1984. Twelve-hour mean O_3 concentrations (0800-2000) for each harvest interval averaged between 0.037 ppm and 0.058 ppm for the 7-month O_3-dispensing period (Table 4.1.3.2.). Only 1 hourly mean above 0.10 ppm was recorded in 1984, and 87.2% of all hourly means were below 0.06 ppm (Table 4.1.3.3.). Highest ambient O_3 concentrations were recorded during July and August, but between episodes of elevated O_3 12-h means would decline to between 0.04 ppm and 0.06 ppm for 2-4 day periods (Figure 4.1.3.1.). Twelve and 24-h mean O_3 concentrations for each treatment for each harvest period are given in Table 4.1.3.2. Frequency distributions of mean hourly O_3 concentrations for each treatment are given in Table 4.1.3.3.

Physiological responses. Ozone injury symptoms consisting of interveinal chlorosis appeared in O_3-added treatments 2-6 d after start of O_3 additions in each exposure period. These symptoms progressed to severe chlorosis and bronzing as O_3 exposure continued and concentrations increased. Premature senescence and abscission of older leaves developed in all O_3-added treatments. No O_3 injury symptoms were evident in CF, NF, or AA treatments.

Evidence of water stress was observed in WS plots for all exposure periods except the first (3/19-4/16). Afternoon wilt developed 2-4 weeks after the last irrigation in each growth period. Plants generally recovered in the morning, but isolated tip kill occurred on a few severely stressed stems. Xylem pressure potential (Ψ_1) measurements taken midway and near the end of a harvest period (Table 4.1.3.4) indicated that plants in WS plots developed water deficits in excess of -1.2 MPa between 2-3 weeks after last irrigation. Plants in water-stressed AA plots did not appear to be as severely water stressed as those in open-top chambers. Differences in temperature between ambient air and alfalfa canopies also indicated that plants in WS plots came under increased water stress as plots dried (Table 4.1.3.5). On 27 June, 4 d after last irrigation, canopy temperature differentials were essentially the same between NI and WS plots. On 6 July 13 d after irrigation, when ambient temperatures at solar noon exceeded 40°C, WS plots had average canopy temperatures 7.5°C greater than ambient air, indicating that stomata had closed and transpirational cooling had been reduced. Canopy temperatures of NF x 2.0 treatments were 2.3°C higher than other treatments for both NI and WS plots, indicating that O_3 injury had also reduced transpiration in these plants.

Table 4.1.3.1. Monthly mean pan evaporation (mmd^{-1}) at USDA Cotton Research Station, Shafter, CA

Month	1984	Mean (1975-1983)
April	5.78	5.39
May	9.11	8.56
June	9.90	9.56
July	10.48	8.89
August	9.13	7.27
September	7.75	6.06
October	4.11	3.96

Table 4.1.3.2. The 12- and 24-h mean O_3 concentrations in open-top chambers and AA plots at Shafter, CA, 1984.

	Harvest Interval															
	1 3/19-4/16		2 4/17-5/14		3 5/15-6/11		4 6/12-7/9		5 7/10-8/2		6 8/3-9/5		7 9/6-10/10		Season	
Treatment	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr	12 hr	14 hr	12 hr	24 hr
CF	.013	.010	.015	.013	.017	.014	.017	.014	.018	.014	.018	.014	.014	.011	.016	.013
NF	.034	.021	.039	.027	.046	.031	.053	.034	.054	.032	.050	.031	.040	.024	.045	.028
NF x 1.3	.055	.032	.063	.039	.080	.047	.092	.054	.087	.049	.077	.045	.066	.038	.073	.043
NF x 1.7	.067	.038	.077	.046	.100	.057	.116	.066	.107	.059	.093	.053	.081	.046	.091	.051
NF x 2.0	.080	.045	.094	.054	.119	.068	.140	.078	.128	.069	.111	.062	.098	.054	.109	.061
AA	.037	.024	.042	.030	.051	.034	.057	.037	.058	.036	.053	.034	.043	.027	.049	.032

Table 4.1.3.3. Frequency distributions of hourly O_3 concentrations for each O_3 treatment from 19 April to 10 October, 1984.

Shafter - Alfalfa
1984
3/19 - 10/10
24-Hour Day

O_3 Concentration Ranges (ppm)	CF	NF	NF x 1.3	NF x 1.7	NF x 2.0	AA
.000<= OB <= .010	10228(41.8%)	6540(26.7%)	5038(25.7%)	5123(26.2%)	4967(25.4%)	2277(23.3%)
.010 < OB <= .020	10130(41.4%)	4054(16.6%)	3282(16.8%)	3300(16.9%)	3326(17.0%)	1548(15.8%)
.020 < OB <= .030	3629(14.8%)	3219(13.2%)	1994(10.2%)	1858(9.5%)	1907(9.7%)	1295(13.2%)
.030 < OB <= .040	419(1.7%)	3252(13.3%)	1004(5.1%)	916(4.7%)	903(4.6%)	1282(13.1%)
.040 < OB <= .050	49(0.2%)	3036(12.4%)	674(3.4%)	546(2.8%)	466(2.4%)	1232(12.6%)
.050 < OB <= .060	5(0.0%)	2143(8.8%)	748(3.8%)	413(2.1%)	380(1.9%)	902(9.2%)
.060 < OB <= .070	0(0.0%)	1530(6.3%)	1142(5.8%)	454(2.3%)	271(1.4%)	700(7.2%)
.070 < OB <= .080	0(0.0%)	568(2.3%)	1360(7.0%)	724(3.7%)	306(1.6%)	397(4.1%)
.080 < OB <= .090	0(0.0%)	115(0.5%)	1264(6.5%)	819(4.2%)	365(1.9%)	129(1.3%)
.090 < OB <= .100	0(0.0%)	3(0.0%)	1016(5.2%)	1016(5.2%)	499(2.6%)	21(0.2%)
.100 < OB <= .110	0(0.0%)	0(0.0%)	851(4.3%)	855(4.4%)	600(3.1%)	1(0.0%)
.110 < OB <= .120	0(0.0%)	0(0.0%)	773(4.0%)	992(5.1%)	916(3.1%)	0(0.0%)
.120 < OB <= .130	0(0.0%)	0(0.0%)	304(1.6%)	790(4.0%)	896(4.6%)	0(0.0%)
.130 < OB <= .140	0(0.0%)	0(0.0%)	92(0.5%)	692(3.5%)	764(3.9%)	0(0.0%)
.140 < OB <= .150	0(0.0%)	0(0.0%)	20(0.1%)	543(2.8%)	713(3.6%)	0(0.0%)
.150 < OB <= .160	0(0.0%)	0(0.0%)	5(0.1%)	301(1.5%)	651(3.3%)	0(0.0%)
.160 < OB <= .170	0(0.0%)	0(0.0%)	1(0.0%)	150(0.8%)	566(2.9%)	0(0.0%)
.170 < OB <= .180	0(0.0%)	0(0.0%)	0(0.0%)	50(0.3%)	469(2.4%)	0(0.0%)
.180 < OB <= .190	0(0.0%)	0(0.0%)	0(0.0%)	20(0.1%)	283(1.4%)	0(0.0%)
.190 < OB <= .200	0(0.0%)	0(0.0%)	0(0.0%)	5(0.0%)	186(1.0%)	0(0.0%)
OB >= .200	0(0.0%)	0(0.0%)	0(0.0%	0(0.0%)	33(0.2%)	0(0.0%)
Total obs	24460	24460	19568	19568	19568	9784

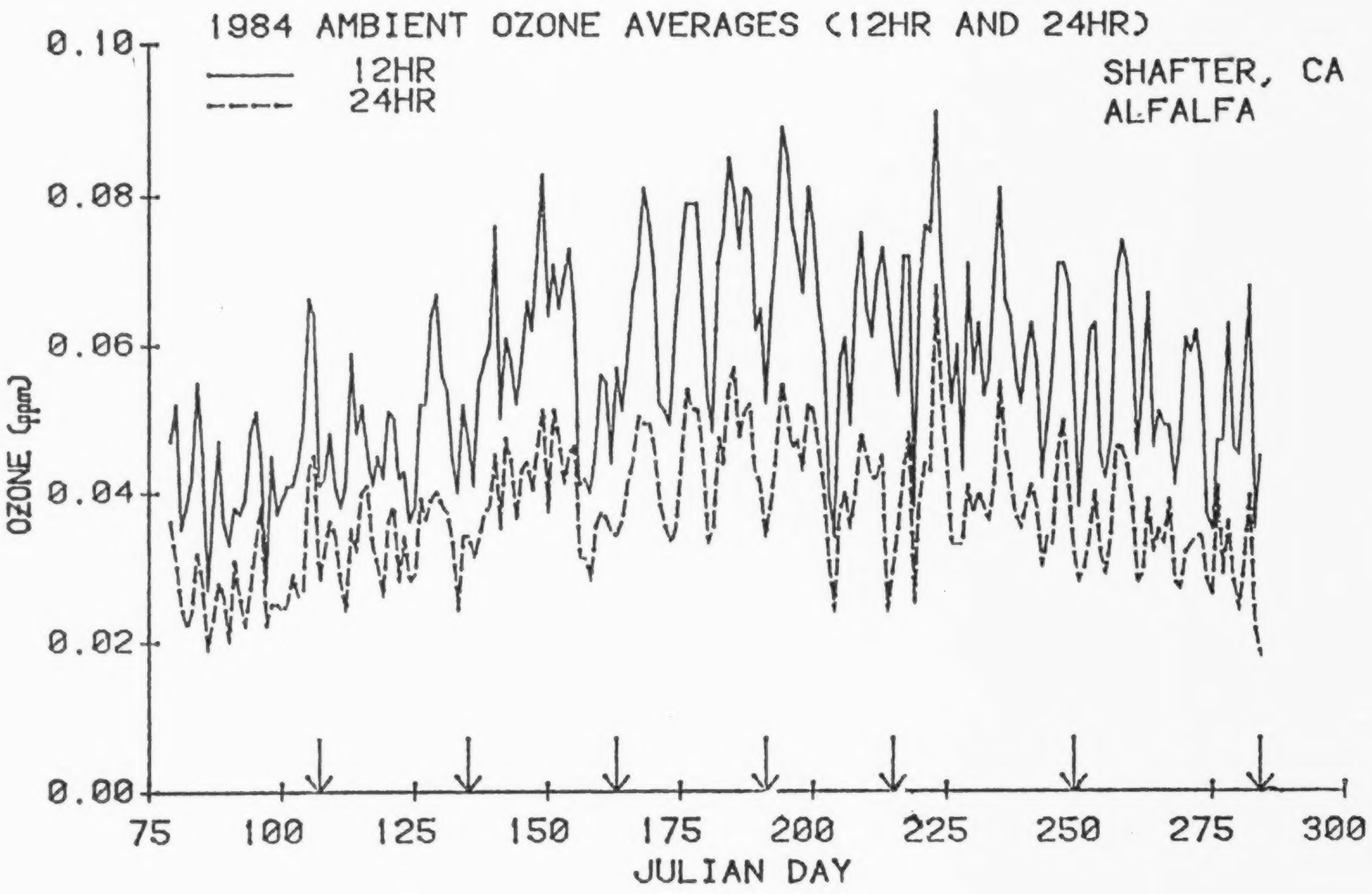

Figure 4.1.3.1. Mean 12-and 24-h ambient O_3 concentrations at Shafter, CA, 19 March - 10 October 1984. Arrows indicate harvest dates.

Table 4.1.3.4. Xylem pressure potential measurements (MPa) of normally-irrigated (NI) and water-stressed (WS) alfalfa grown in open-top chambers at Shafter, CA, 1984; mean of 4 to 6 measurements per treatment; measurements taken at noon.

	Non-stress Period[a]		Stress Period[b]	
	NI	WS	NI	WS
Treatment	(4)[c]	(15)[c]	(6)[c]	(21)[c]
CF	-0.7	-1.1	-0.3	-1.4
NF	-0.6	-0.8	-0.4	-1.3
NF x 1.3	-0.6	-1.1	-0.6	-0.6
NF x 1.7	-0.7	-1.0	-0.8	-1.2
NF x 2.0	-1.0	-1.1	-0.5	-1.3
AA	-0.7	-0.7	-0.5	-0.8

[a] Soil moisture levels sufficient to replenish water lost through transpiration in NI and WS plots.

[b] Soil moisture levels in WS plots reduced below wilting point. NI plots were not water-stressed because soil moisture was replenished by irrigation.

[c] Days from last irrigation.

Table 4.1.3.5. Temperature differentials ($C^{\circ}_{canopy}-C^{\circ}_{air}$) at solar noon between ambient air at canopy height and closed canopies of normally-irrigated (NI) and water-stressed (WS) alfalfa exposed to O_3 in open-top chambers at Shafter, CA; means of 4 to 6 measurements per treatment.

	27 June		6 July	
Treatment	NI (2)[a]	WS (4)[a]	NI (11)[a]	WS (13)[a]
CF	-7.7	-7.5	-7.5	+0.8
NF	-7.8	-7.7	-3.5	+0.8
NF x 1.3	-7.4	-7.2	-8.1	+1.7
NF x 1.7	-6.7	-6.2	-3.7	-1.5
NF x 2.0	-5.8	-4.5	-3.4	+2.5
AA	-7.4	-8.0	-7.7	-2.9

[a] Days from last irrigation.

The effects of O_3 on stomatal conductance and transpiration of alfalfa are shown in Figures 4.1.3.2 and 4.1.3.3, respectively. Data were collected on 19 July 1984, 7 d after last irrigation. Conductance in all NI treatments except NF x 2.0 increased at the same rate until shortly after 1000 (Figure 4.1.3.2). CF plants continued to open stomates until 1400, and had maximum rates of conductance 40% greater than NF plants. Conductance in NF and NF x 1.3 plants peaked between 1200-1300, then gradually declined until 1800, when decreased light intensity caused rapid stomatal closure. Conductance in NF x 1.7 plants showed a "noon drop," an increase at 1400, then a gradual decline. Plants in the high O_3 treatment had greatly reduced stomatal conductance, averaging half the maximum conductance of CF plants. Stomata also opened more slowly in the morning and closed sooner than those of other O_3 levels. Diurnal changes in rates of transpiration were very similar to those of stomatal conductance (Figure 4.1.3.3). Total daily transpiration decreased linearly with increased exposure to O_3. Daily transpiration was 14% lower in NF and 46% lower in NF x 2.0 plots compared with CF treatments.

Rates of photosynthesis, in NI treatments, also decreased linearly with increased O_3 dose (Figure 4.1.3.4). On the day these data were collected (26 September 1984) NI and WS plants did not differ significantly in rate of photosynthesis, except for CF chambers, where WS plots averaged 37% lower than NI plots. Rates of photosynthesis in NF x 2.0 plots averaged 53% of those of CF plots in the NI treatments, similar to the amount of reduction in transpiration (46%). In WS plots, the difference in rates of photosynthesis between CF and NF x 2.0 plots averaged 49%

Yield responses. Alfalfa yields for the seven harvests in which O_3 was dispensed are given in Table 4.1.3.6. Exposure to O_3 reduced yield in all harvests and the amount of yield reduction was roughly proportional to O_3 dose. For NI plots, yield reductions increased linearly until the fourth harvest (9 July) (Figure 4.1.3.5); yield reductions remained stable from the fourth to seventh harvests, averaging 25%, 40%, and 48% of CF yields for NF x 1.3, NF x 1.7, and NF x 2.0 treatments, respectively. Except for harvest six (5 September), yields of NF and AA plots were similar, and both averaged about 5% below those of CF plots. Yields of WS plots were lower than those of NI plots, averaging 12.4% lower for CF treatments, 29.8% lower for NF treatments, and 10.3% lower in AA plots. Ozone did not reduce yield significantly until the fourth harvest (9 July), after which yield reductions stabilized (Figure 4.1.3.6). Reductions averaged 32%, 36%, and 51% for NF x 1.3, NF x 1.7, and NF x 2.0 treatments, respectively, compared with CF plots. Yield reductions in NF-WS plots were greater than those in NF-NI plots, averaging 12.6% for the season, compared with 4.5% for NI plots. Yields in AA plots did not correspond with those of NF treatments, as in NI plots, but averaged 13.5% greater over the season. Also, water stress tended to accentuate the O_3 effect on the NF treatment.

Analysis of variance of seasonal yield data from each plot showed highly significant O_3 and water stress effects on yield, but the interaction between O_3 and irrigation was not significant (Table 4.1.3.7). Polynomial regression between seasonal yields in each plot and seasonal mean 12-h O_3 concentrations indicated a significant quadratic

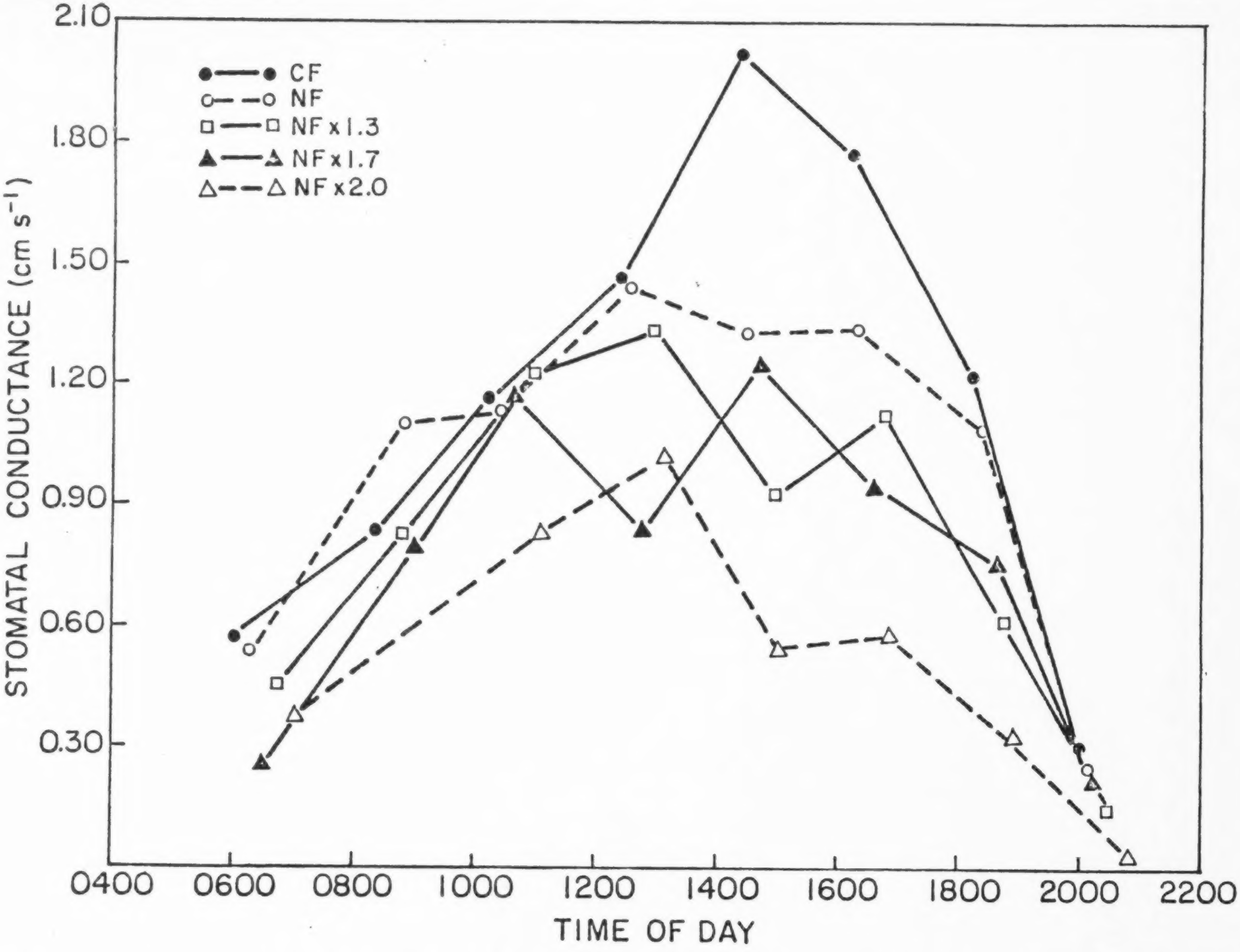

Figure 4.1.3.2. Diurnal curves of total (abaxial + adaxial) stomatal conductance of normally irrigated (NI) alfalfa exposed to O_3 in open-top chambers, Shafter, CA, 19 July 1984; data points are means of 5 samples per chamber.

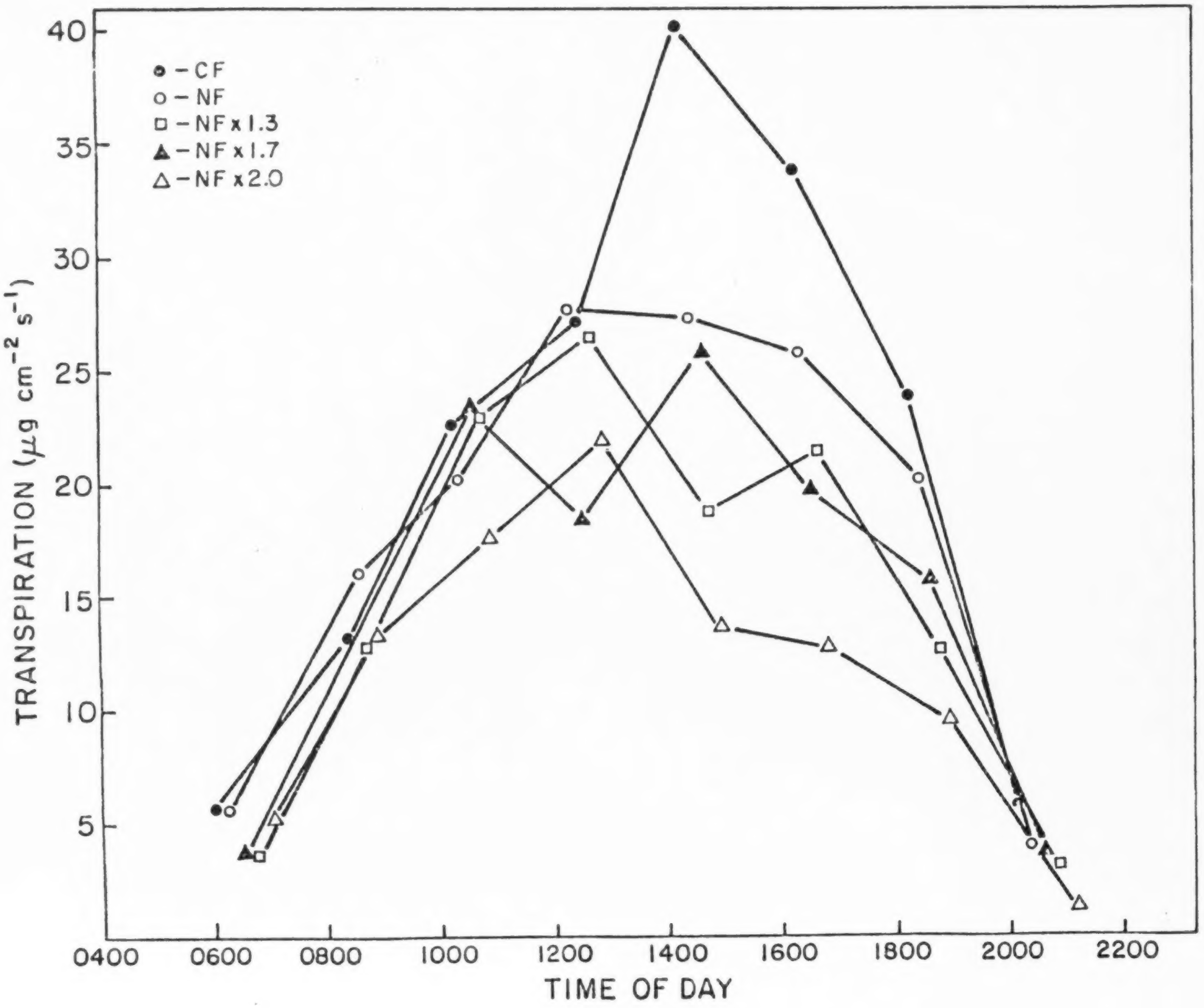

Figure 4.1.3.3. Diurnal curves of total transpiration of normally irrigated (NI) alfalfa exposed to O_3 in open-top chambers, Shafter, CA, 19 July 1984; data points are means of 5 samples per chamber.

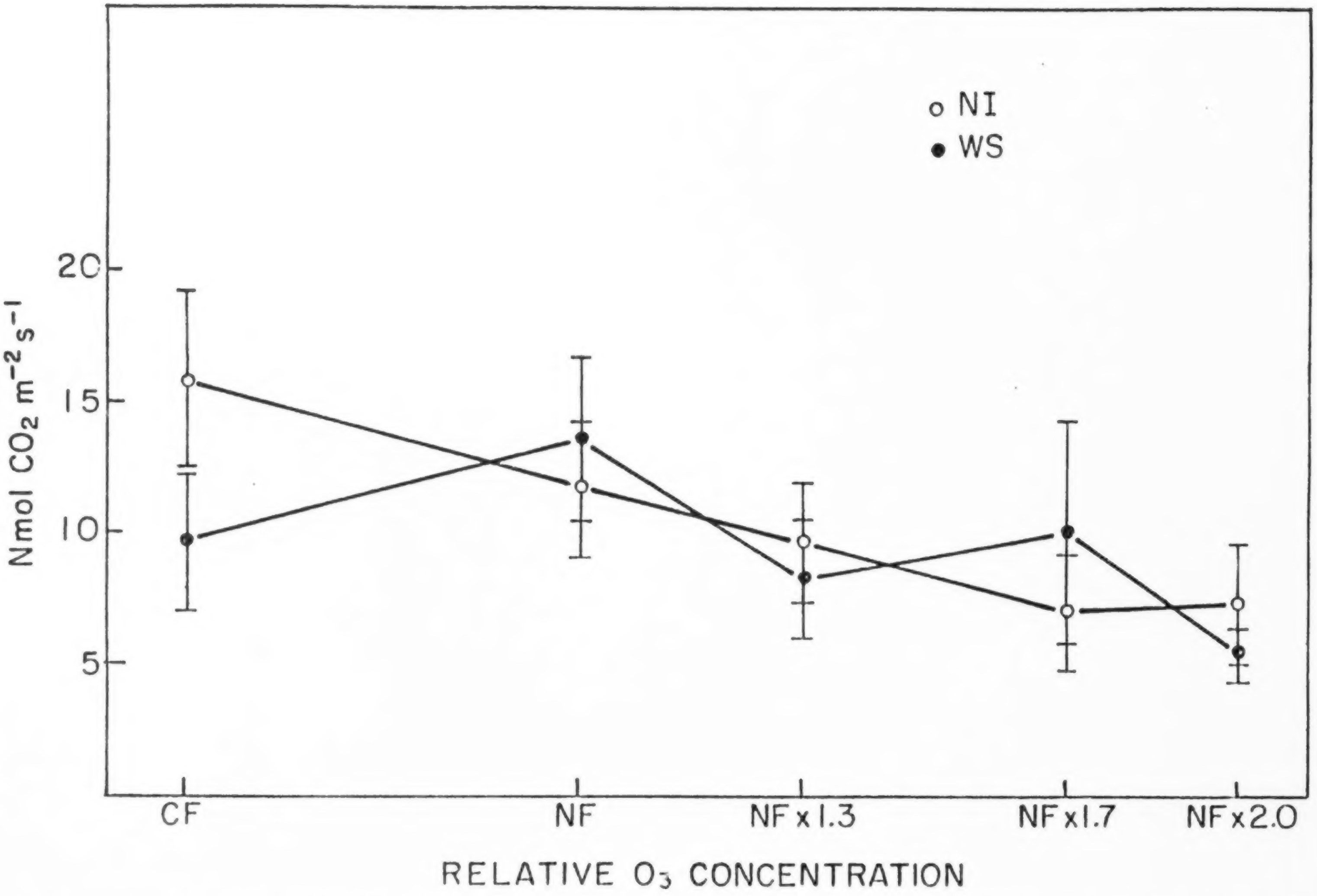

Figure 4.1.3.4 Photosynthetic rates of normally-irrigated (NI) and water-stressed (WS) alfalfa exposed to O_3 in open-top chambers, Shafter, CA; 26 September 1984; data points are means of 8 samples per treatment ± 1 standard deviation.

Table 4.1.3.6. Harvest data for alfalfa grown in open-top chambers at Shafter, CA and exposed to incremental concentrations of O_3 from 15 March to October 1984. Data are in g m^{-2} d.m., mean of three treatments (CF, NF, AA) or two replicates/treatment.

TRT	Harvest Date[a/]						
	4/16	5/14	6/11	7/9	8/2	9/5	10/10
	I. Normal irrigation						
CF	483	506	431	464	396	297	348
NF	493	489	404	426	389	261	330
NF x 1.3	474	489	374	340	291	225	240
NF x 1.7	467	437	306	263	239	177	210
NF x 2.0	445	406	276	244	214	161	167
AA	522	497	396	427	379	335	327
	II. Water stressed						
CF	490	447	370	332	284	292	347
NF	454	380	338	279	231	245	311
NF x 1.3	474	360	339	229	200	203	224
NF x 1.7	439	420	321	213	197	192	197
NF x 2.0	438	361	321	166	151	139	155
AA	489	428	356	347	309	325	332

[a/] Harvest data can be converted to kg ha^{-1} by multiplying by 11.5.

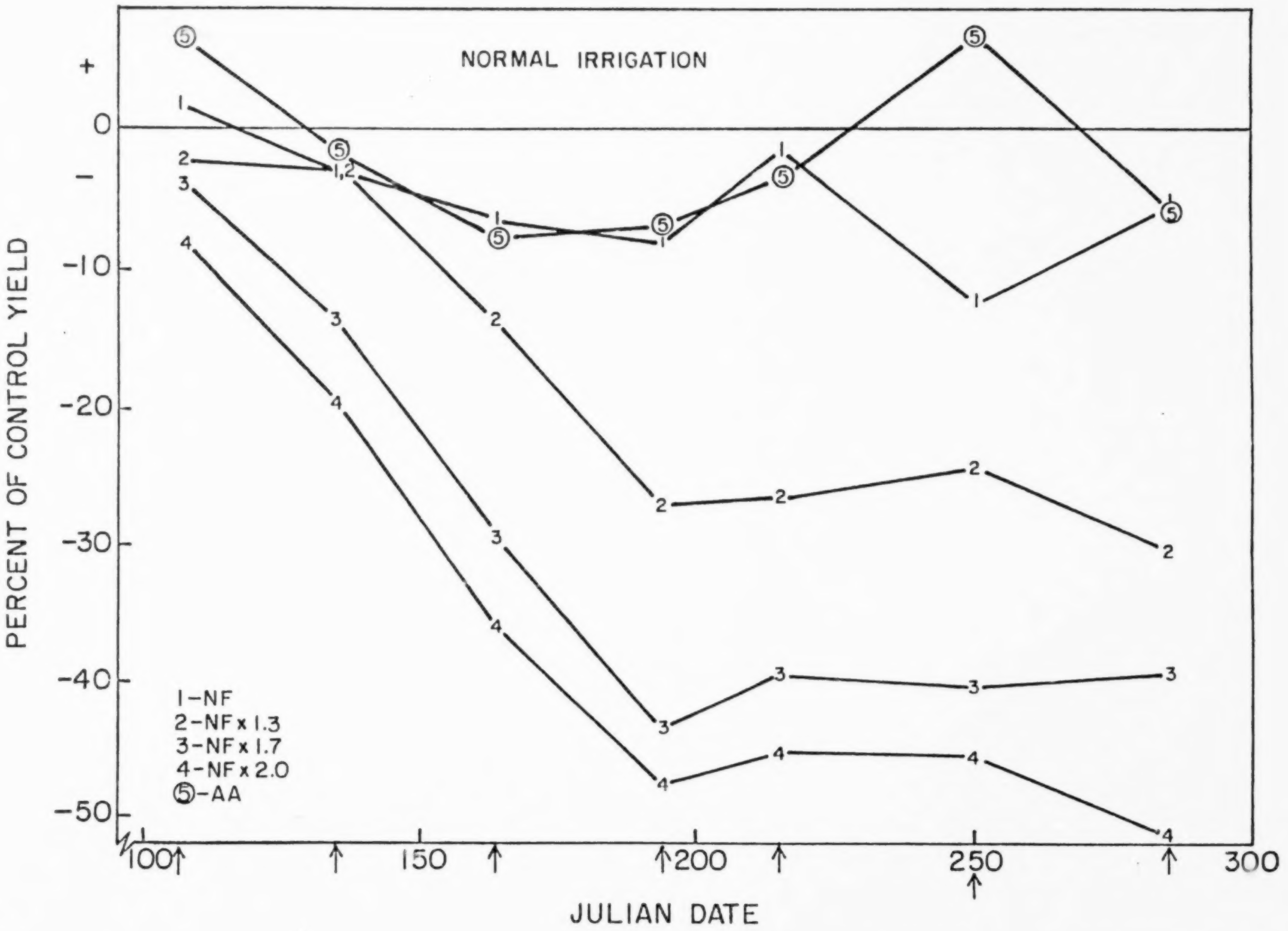

Figure 4.1.3.5 Yields of normally-irrigated alfalfa expressed as per cent of control (CF chamber yield) for 7 harvests during O_3-dispensing season (19 March - 10 October 1984).

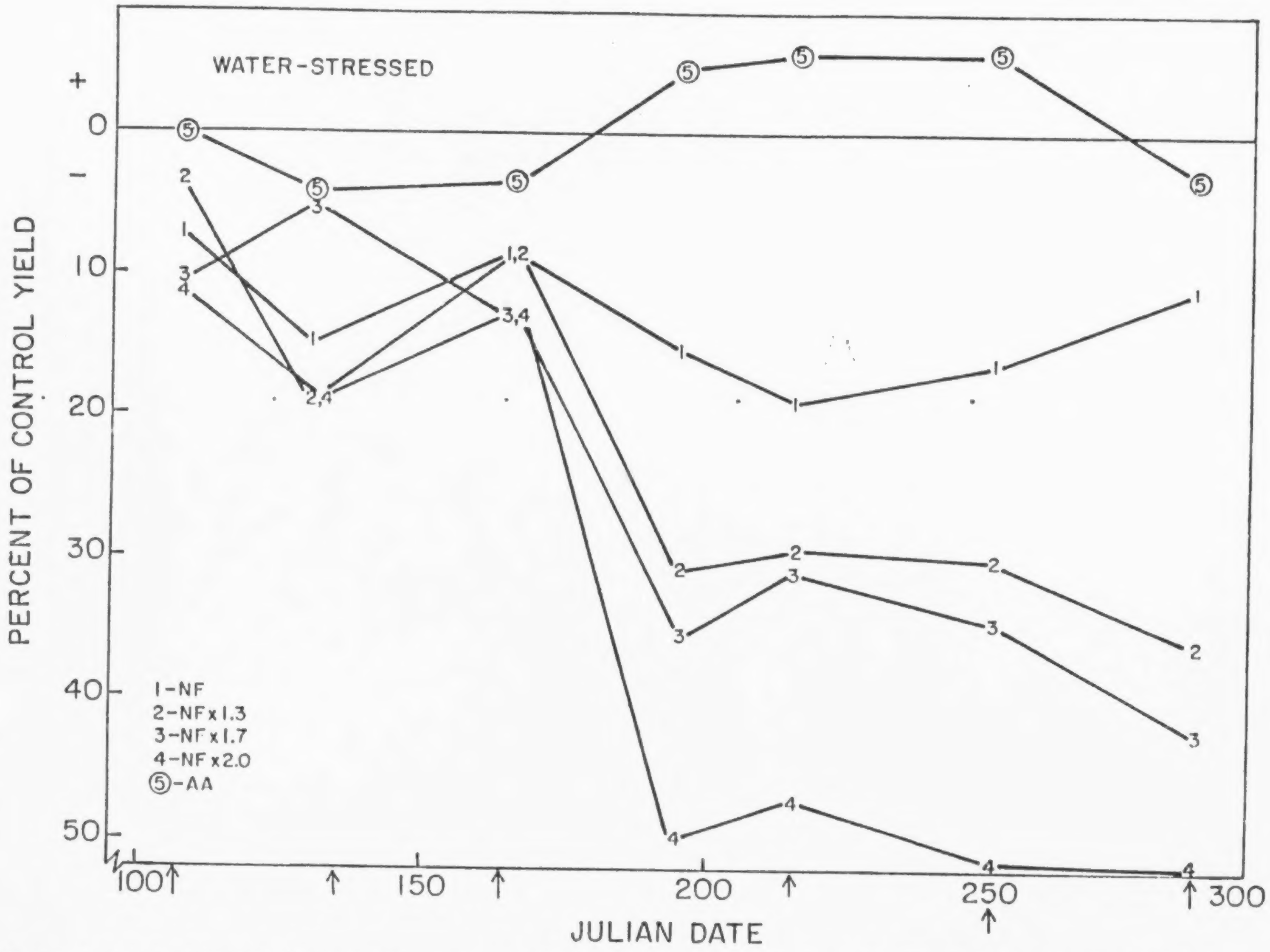

Figure 4.1.3.6 Yields of water-stressed alfalfa expressed as per cent of control (CF chamber yield) for 7 harvests during O_3-dispensing season (19 March - 10 October 1984).

Table 4.1.3.7. Analysis of variance mean squares for total seasonal yield of alfalfa (g m^{-2} d.m.) harvested in open-top chambers in Shafer, CA during O_3-dispensing season.

Source of variation	d.f.	Mean squares	F
Irrigation level (I)	1	702126	22.6*** [a]
Ozone (O)	4	662869	21.3***
I X O	4	39366	1.3 (N.S.)
Error	14	31108	

[a] *** is significant at the 0.1% level.

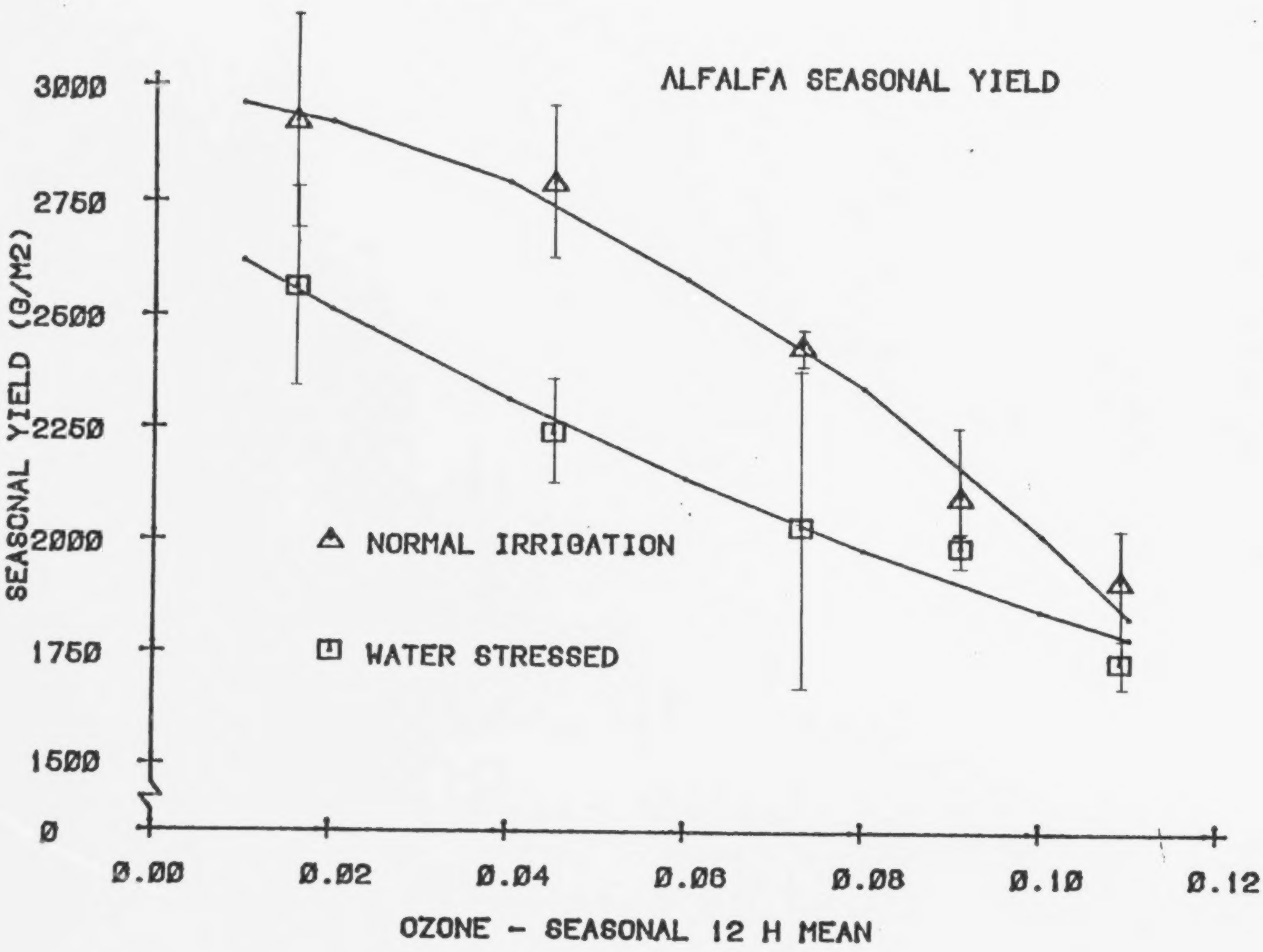

Figure 4.1.3.7. Dose-response curves for total seasonal yield (19 March - 10 October 1984) of NI and WS alfalfa exposed to O_3 in open-top chambers at Shafter, CA. Data points are treatment means ± 1 standard deviation. Equations for fitted curves are in Table 4.1.3.8.

response to O_3 in NI plots while the dose-response curve in WS plots was linear (Table 4.1.3.8). Thus, differences in yield between NI and WS plots were more pronounced at lower O_3 concentrati[illegible] than at higher O_3 levels. Regression between seasonal yie[illegible] seasonal 12-h O_3 means using the Weibull function indicated that regression equations for NI and WS treatments were homogeneous, if a factor accounting for differences in yield between NI and WS plots were added to the equation. Regression equations using both polynomial and Weibull models are given in Table 4.1.3.8.

Total percent dry weight of protein did not differ among treatments at any of the harvests.

4.1.3.4. Discussion and conclusions. Alfalfa in these experiments was grown under two water regimes; one (NI) in which plants were not allowed to exceed xylem pressure potentials (Ψ_1) of -1.2 MPa (wilting point) and one in which plots were allowed to dry until Ψ_1 exceeded -1.2 MPa at noon (WS). These WS plants experienced drought stress for a 1-to 3-week period prior to harvest. Under these conditions NI alfalfa showed a quadratic response to increasing O_3 dose, with relatively little response near ambient O_3 concentrations but with increasing yield losses at higher O_3 cconcentrations. On a seasonal yield basis NF chambers showed a 4.5% loss of yield and NF x 2.0 chambers had 35.1% yield loss compared with CF chambers. Yield responses to O_3 in WS plots were nearly linear, with stressed plants showing relatively less response to O_3 at the highest O_3 concentrations compared with NI plants. Seasonal yield of WS-NF chambers was reduced 12.6% and NF x 2.0 yields were reduced 32.0% compared with CF chambers.

These differences in response of NI and WS alfalfa to O_3 can be explained in terms of the pattern of ambient O_3 episodes during 1984. Periods of daily mean O_3 concentrations exceeding 0.06 ppm alternated with intervals of two to several days in which mean O_3 concentrations were low. If an O_3 episode occurred during the first two weeks of an irrigation cycle then NI and WS plants responded similarly. If the O_3 episode occurred during the period in which WS plots were under stress then these plants had a reduced response to O_3 because stomata were closed and gas exchange was reduced. The NI plants were fully susceptible to O_3 during this period, so these plants experienced greater O_3 flux throughout the season and thus showed a greater overall response to higher seasonal mean O_3 concentrations. Conversely, if periods of low O_3 occurred during non-stress times, then both NI and WS plants could grow at a normal rate. If low O_3 periods came during a stress interval for WS plots then NI plants could continue rapid growth and recover from O_3-induced growth reduction to some extent. However, WS plants could not resume normal growth during this period because lack of water was restricting growth, so recovery was less than that in NI plots. Averaged over a growing season, these cycles of growth and O_3-induced growth reduction resulted in greater overall yield reductions in WS plants at low O_3 concentrations (near ambient and below) and greater growth reductions in NI plants at high seasonal O_3 concentrations (0.08 ppm or above). Thus, O_3-drought stress interactions in alfalfa were a complex function of plant water status and O_3 exposure dynamics.

Table 4.1.3.8. Least squares best fit regression equation for seasonal yield of alfalfa (in g m^{-2} d.m.) and seasonal 12 h (0800-2000) O_3 concentrations in open-top chambers at Shafter, CA (19 March - 10 October, 1984).

I. Polynomial model

Normal irrigation

$$\hat{Y} = 2948 - 93506[O_3]^2 \qquad R^2 = 0.89$$

$$(\pm\ 10627)^{\underline{a}/}$$

Water-stressed

$$\hat{Y} = 2662 - 8276[O_3] \qquad R^2 = 0.79$$

$$(\pm\ 1351)$$

II. Weibull model

$$\hat{Y} = (2592 + 418 \cdot M)\ e^{-\left(\frac{[O_3]}{0.187}\right)^{1.57}}$$

$$(\pm\ 109) \quad (\pm\ 82) \qquad (\pm\ 0.030) \quad (\pm\ 0.47)$$

M = 0 if water-stressed

M = 1 if normally irrigated

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[a] Figures in parenthesis are standard errors.

4.2 EFFECT OF SO_2 ON O_3 DOSE-RESPONSE RELATIONSHIPS

4.2.1. Effects of O_3 and SO_2 on the Physiology and Yield of a Crop of Red Clover and Timothy (NERCLAP)--Robert J. Kohut, Robert G. Amundson, and J. A. Laurence

4.2.1.1 Introduction

The 1984 NCLAN field program at Boyce Thompson Institute was the first year of a two-year study on mixed forage and was the second year of a three-year program that integrated crop loss studies sponsored by the Environmental Protection Agency and the Electric Power Research Institute. The combined support from the two funding agencies allowed for expansion of the NCLAN studies to develop O_3 dose-response functions for yield and quality for the mixed forage crop to include several additional studies. The goals of the combined program were to 1) evaluate dose-response relationships for yield of the red clover and timothy hay crops exposed to O_3 alone, SO_2 alone, and the two pollutants combined; 2) assess nutrient qualities of the crop harvested from each of the air pollutant treatments; and, 3) assess the effects of the treatments on stomatal conductance, chlorophyll contents, and photosynthesis of red clover.

4.2.1.2. Materials and methods

Cultural Practices. A mixed stand of hay consisting of red clover (*Trifolium pratense* L. cv. 'Arlington') and timothy (*Phleum pratense* L. cv. 'Champlain') was drilled on August 16, 1983. The field had been pretreated with Round-up herbicide at 7.1 l/ha and fertilized with 10-20-20 (NPK) at 227 kg/ha. Seed of the two species was combined at equal weights and applied at a rate of 14.75 kg/ha. The ratio of timothy to clover seed was approximately 4.5:1. Prior to planting, the clover seed was inoculated with Nitragin, a commercial rhizobium product, at the rate of 41 g/kg of seed.

Soils in the experimental plot are in the Collamer and Niagara series, both of which are Haplaudalfs. The soils are characterized as silt loams. Tensiometers were placed in all plots at a depth of 30.5 cm to monitor soil moisture. Readings were taken three times each week and all plots irrigated when readings began to exceed 70 in several plots. Irrigation was conducted on July 20 and 21 and August 10. All plots received 5.0 cm of water at both irrigations. Malathion was applied on July 28 to control aphids on the experimental plots.

Pollutant Treatments and Monitoring. The study used four levels of O_3, four levels of SO_2, and all combinations of the two pollutants. The O_3 treatments consisted of charcoal-filtered air (CF), nonfiltered air (NF), and nonfiltered air with the proportional addition of O_3 to attain 1.5 and 2.0 times the ambient concentration (1.5X and 2.0X, respectively). Additions were made for 12 hr/day (0800 to 2000 EDT) when ambient O_3 concentrations were greater than 0.03 ppm. Standard NCLAN protocols were followed for rain periods and blower shut-down at night.

Sulfur dioxide exposures simulated the concentration, duration, and frequency dynamics associated with point sources. Ambient SO_2 monitoring data for the Shawnee Steam Plant for the 1976, 1978, and 1982 growing seasons were obtained from the Tennessee Valley Authority. The frequency distribution of concentrations and the exposure dynamics for each year served as the basis for developing an SO_2 treatment since each year represented a different level of emission control at the power plant (Table 4.2.1.1). Each exposure in each treatment had a unique duration and pattern of changing SO_2 concentrations. The fourth treatment level consisted of no SO_2 addition.

The O_3 and SO_2 generation and distribution systems were similar to those used in previous NCLAN studies. Ozone monitoring was conducted with Monitor Labs Model 8410 instruments and SO_2 was monitored with TECO Model 43 instruments. All monitors were subject to the NCLAN quality assurance program. Pollutant monitoring used a time-sharing system where each observation was 2 min in duration and each plot was sampled two or three times each hour. The sample stream was split after passing through the sequencing valve and entered both the O_3 and SO_2 monitors. All sample lines were Teflon. Line efficiencies were determined three times during the study and were taken into account during the fumigations and the reduction of monitoring data. Monitoring data were recorded with a Hewlett-Packard Model 85 computer and data logger with strip charts used as back-up.

The forage stand was evaluated for uniformity in the spring and 36 plots were selected. The experiment was a 4 X 4 X 2 factorial requiring 32 open-top chamber plots. The four additional plots were ambients. Treatments were randomly assigned to 18 plots in each of two blocks. Plastic was placed on the chamber frames and blowers started by June 5. A pre-treatment harvest of each experimental plot was conducted on June 11-13 at clover flowering to establish baseline yield and quality values. A period of time was allowed for plant recovery and O_3 additions were initiated on June 28. The final fumigation of the study was conducted on September 28. During this 92-day period, O_3 additions were made on 83 days and SO_2 exposures were conducted on 35 days.

Treatment harvests were conducted on August 9-10 and October 3-4. Harvest data were obtained from two permanently marked 0.5 m^2 quadrats in each chamber and ambient plot. Plants in each quadrat were cut approximately 10 cm above the ground and immediately separated by species. Plant material was oven-dried at 80°C for 48 hr, weighed, and analyzed for nutrient content and elemental composition. Analyses were conducted by the Forage Testing Laboratory of the New York Dairy Herd Improvement Cooperative in Ithaca, NY.

Physiology. Because there were 16 treatments, evaluations of changes in stomatal conductances and rates of photosynthesis were made only on red clover. The studies were conducted between the first and second harvests when the plants were growing the most rapidly and when ambient O_3 concentrations, and consequently all O_3 treatment levels, were the highest. Ten to 20 of the youngest expanded clover leaves in each treatment were tagged weekly to enable measurements to be taken on leaves

Table 4.2.1.1 Frequency distributions of the hourly SO_2 concentrations in the three target treatments derived from air monitoring data obtained from the Tennessee Valley Authority.

SO_2 Concentration (ppm)	Number of Hours of Exposure		
	High	Medium	Low
0.00	2525	2630	2688
0.05	131	76	48
0.10	18	21	10
0.15	11	10	2
0.20	8	2	1
0.25	5	4	1
0.30	2	1	
0.35	5	3	
0.40	4	2	
0.45	3	0	
0.50	1	1	
0.55	2		
0.60	3		
0.65	0		
0.70	3		
0.75	1		
0.80	1		
0.85	2		
0.90	2		

of the same age and to follow changes in net photosynthesis, stomatal conductance, and chlorophyll contents with time. Stomatal conductances of upper and lower leaf surfaces were monitored with a steady-state porometer (LI-COR model 1600).

Rates of photosynthesis were assessed by two techniques: the uptake of $^{14}CO_2$ and the evolution of O_2. The rate of CO_2 fixation was assessed by exposing a portion of an intact leaf to an atmosphere with known CO_2 concentration and $^{14}CO_2$ activity for a fixed period of time. The disc was immediately excised and put into a solubilizing liquid and then placed in a scintillation counter to determine the activity of the ^{14}C in the tissue. The amount of ^{14}C present in the tissue is proportional to the rate of CO_2 fixed during the exposure interval (18a).

Rates of oxygen evolution and consumption were determined by the following method. Leaf discs (0.33 cm^2) were cut from selected leaves with a hole punch and transferred to a temperature controlled glass sample cell (Gilson Medical Electronics #01271002) containing a solution of 0.33M sucrose, 50 mM hepes (pH 7.6), 10 mM $NaHCO_3$, and 1 µl Tween 20. The sample cell volume was 2 ml. Leaf discs were submerged in a 25°C solution and held perpendicular to a light source (Fiber-Lite, Bausch and Lomb) by 22 gauge wire. Oxygen evolution was determined polarographically using an O_2 electrode (YSI #5331 oxygen probe) with a polarizing voltage of 0.8 volts. Oxygen consumption (respiration) was determined by completely darkening the cell and following the loss of O_2 from the solution. Probe sensitivity and span calculations were determined at the beginning and end of each day by measuring electrode output in H_2O equilibrated with ambient O_2 at 25°C, and H_2O equilibrated with ambient O_2 at 25° C and then depleted of O_2 by the addition of 1.0 mg $Na_2S_2O_4$.

Following the measurement of O_2 evolution, the discs were transferred to test tubes containing 2 ml of 80% acetone and held on ice for chlorophyll determinations. Leaf discs were ground in cold 80% acetone by a "polytron" (Type PT10/35 Brinkman Instruments) for a period of 30 seconds. After grinding, the liquid sample was quantitatively transferred to a centrifuge tube and centrifuged at 7300 rpm for a period of 5 minutes (Model CL, International Clinical Centrifuge). All samples remained on ice during preparation. Spectrophotometric determinations of chlorophyll concentrations were made on samples at room temperature (approx. 22°C) using a Perkin-Elmer Lambda 5 UV/visible spectrophotometer that measured absorbance at A647 and A667. Chlorophyll a and b concentrations were calculated using the equations of Arnon (18b).

Dose-response. The dose-response analyses used the harvest data from the 16 treatments of O_3 and SO_2 in the open-top chambers. Analyses were conducted using the combined yields of both species from each plot for the combined harvests. Regression analyses were conducted using the Weibull and alternative models to evaluate their suitability.

4.2.1.3. Results

Pollutant Monitoring. The hourly O_3 and SO_2 monitoring data were analyzed to characterize the exposure treatments. The O_3 treatments are presented in Table 4.2.1.2. Data for both 12-h and 7-h periods are presented for comparison. The diurnal pattern of the seasonal hourly O_3 concentrations reflects the effects of the proportional controller and the extended daily fumigation period in the smooth transitions of increasing and decreasing O_3 concentrations in the O_3-addition treatments (Figure 4.2.1.1). The theoretical cumulative frequency of the hourly O_3 concentrations for the chamber treatments using the proportional controller are presented in Figure 4.2.1.2. The actual cumulative frequency distributions of the hourly O_3 concentrations for each treatment during the 12-h daily exposure period are presented in Figure 4.2.1.3.

Cumulative frequency distributions were developed for the target SO_2 treatments (Figure 4.2.1.4) and compared with the distributions produced in the actual exposures (Figure 4.2.1.5). The target and actual distributions for each treatment were similar. In addition, the frequency distributions for the treatments indicated that they constituted distinctly different levels of exposure. The SO_2 treatments were characterized by calculating the average 24-h concentration, the average daily 1-h maximum concentration, the first and second 1-h maximum concentrations, and the cumulative ppm-h. These data are presented in Table 4.2.1.3.

Effects of Ozone on Physiology. Stomatal conductance. Stomatal conductances of both leaf surfaces of red clover declined with exposure to increasing concentrations of O_3 (Figure 4.2.1.6), but the percentage decline was smaller than that previously found for soybean, kidney bean, and wheat.

Photosynthesis and respiration. Rates of $^{14}CO_2$ fixation declined dramatically with exposure to increasing concentrations of ozone (Table 4.2.1.4). For example, plants exposed to the highest O_3 concentrations had an average rate of photosynthesis that was about two-thirds that of plants exposed to charcoal-filtered air (697 vs 393 μmoles CO_2 fixed dm^{-2} h^{-1}, respectively). These values were taken on leaves that were of equal age.

In general, as leaves aged, rates of photosynthesis declined and the differences in rates between treatments increased (Figure 4.2.1.7). The shape of the curves for effect of leaf age on photosynthesis in the CF and NF treatments was essentially the same with a slight increase in rate of photosynthesis at the second and third youngest leaves and then a pronounced decline as the leaves aged. For the 1.5x treatment level, the decline in rate of photosynthesis occurred in leaves older than the second youngest leaf while in the 2.0x treatment the rates of photosynthesis declined with any increase in age.

Oxygen evolution increased in response to exposure to increasing concentrations of O_3 from about .047 to .079 μmoles O_2 per hr per mg chlorophyll in the CF versus the 2.0x ambient O_3 treatments, respectively (Table 4.2.1.4). Oxygen evolution also increased with increasing leaf age but the rate of increase was greater in leaves exposed to the higher concentrations of O_3 (Figure 4.2.1.8.). The ratio of O_2 evolved per

Table 4.2.1.2. Treatment-level characterizations of the seasonal O_3 exposure regimes in the 1984 red clover and timothy study at Ithaca, NY (concentrations in ppm).

	12-h			7-h			Daily 1-h High Conc.			12-h	
Treatment	Avg	Max	2nd Max	Avg	Max	2nd Max	Avg	Max	2nd Max	# Hr >.08	# Hr >.12
CF	0.019	0.041	0.037	0.022	0.048	0.042	0.037	0.082	0.078	1	0
AA	0.036	0.070	0.069	0.040	0.081	0.076	0.058	0.086	0.085	7	0
NF	0.036	0.067	0.064	0.041	0.076	0.073	0.052	0.085	0.084	8	0
NFx1.5	0.050	0.100	0.096	0.057	0.112	0.110	0.075	0.127	0.126	265	8
NFx2.0	0.062	0.127	0.127	0.071	0.146	0.139	0.094	0.169	0.160	512	148

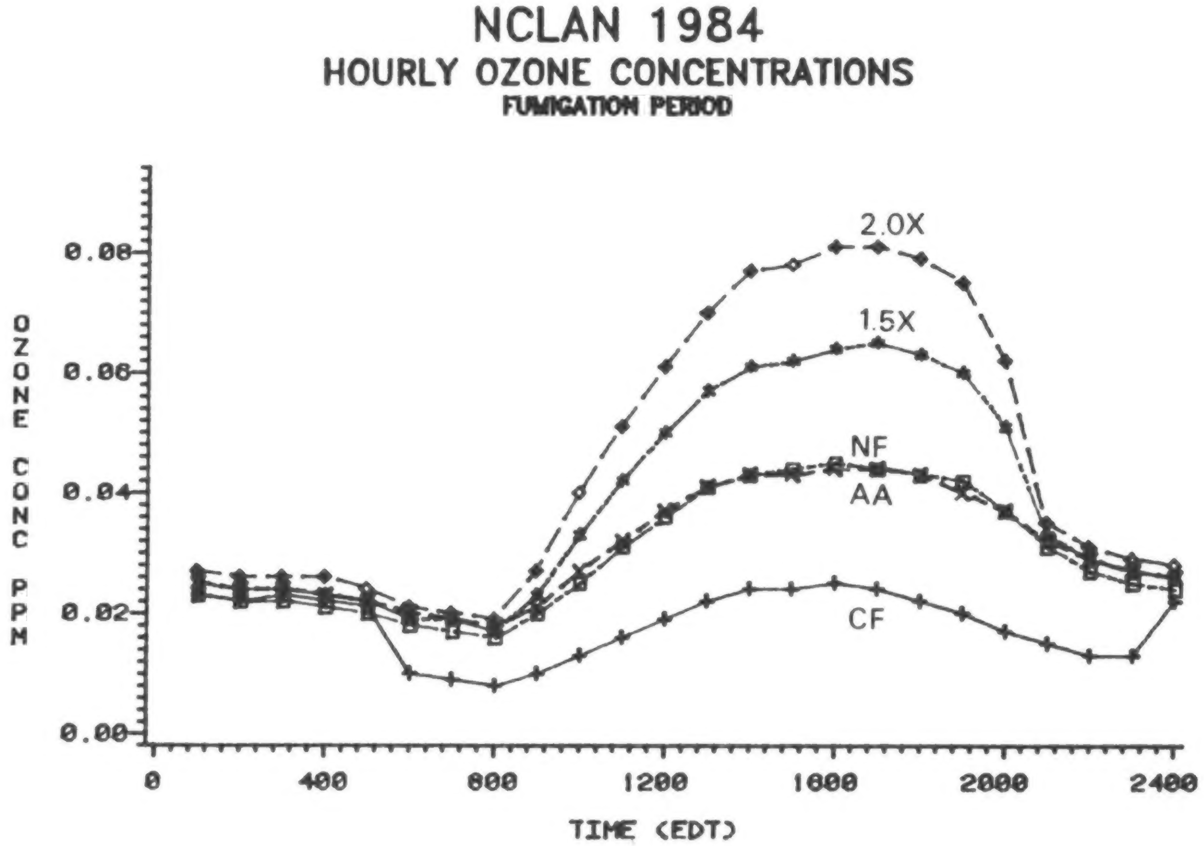

Figure 4.2.1.1. Diurnal pattern of the hourly O_3 concentrations during the red clover and timothy experiment for each treatment level.

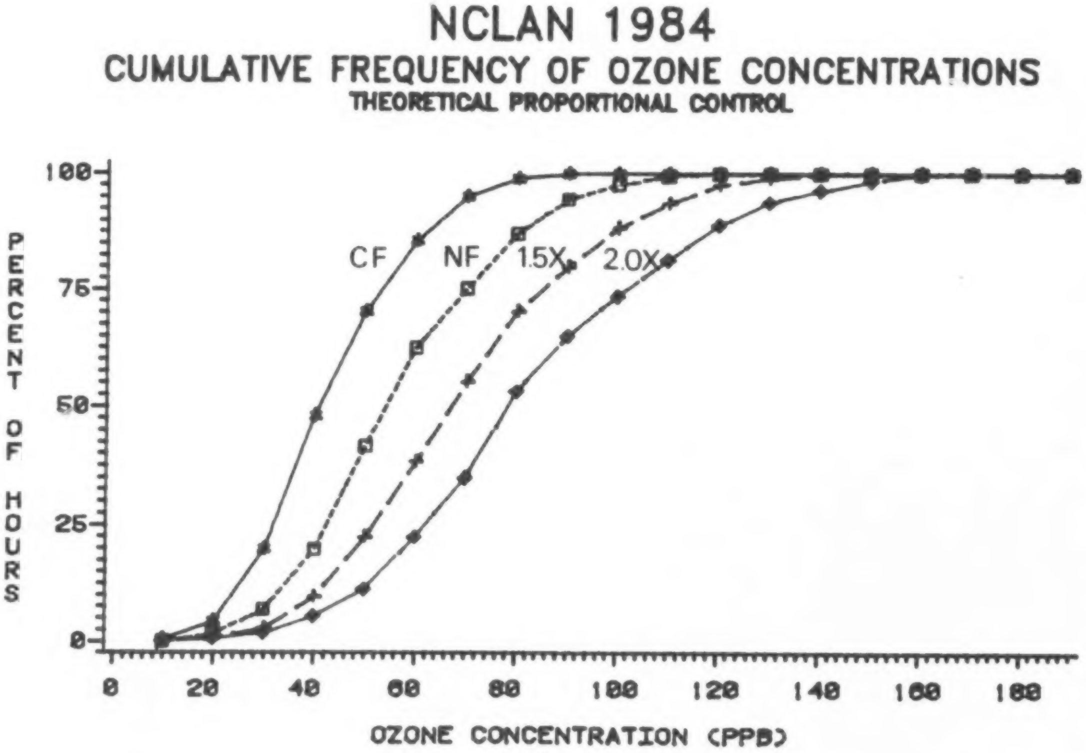

Figure 4.2.1.2. Theoretical cumulative frequency distributions of the hourly O_3 concentrations produced with the proportional controller for the chamber treatments.

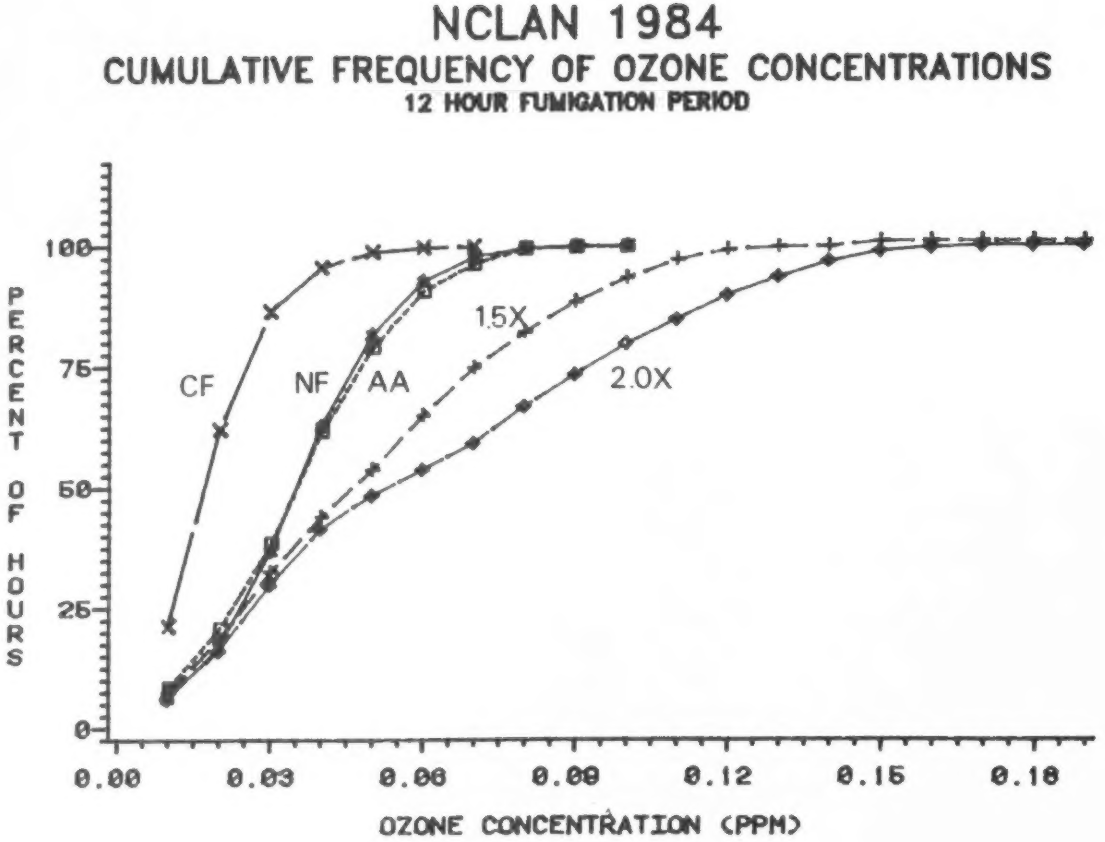

Figure 4.2.1.3. Actual cumulative frequency distributions of the hourly O_3 concentrations produced with the proportional controller during the 12-h exposure period for the chamber and ambient treatments.

Table 4.2.1.3. Treatment-level characterizations of the seasonal SO_2 exposure regimes in the 1984 red clover and timothy study at Ithaca, NY. All concentration in ppm.

Treatment	24-h Avg for Exposure Days	24-h Avg for All Days	Avg Daily 1-h Max for All Days	Max 1-h	2nd Max 1-h	Cumulative ppm-h [a]
Ambient	0.004	0.002	0.016	0.115	0.108	2.24
Low	0.005	0.003	0.027	0.162	0.158	2.89
Medium	0.008	0.005	0.049	0.387	0.373	4.60
High	0.016	0.011	0.109	0.833	0.728	9.30

[a] Calculated from the average SO_2 concentration for each exposure.

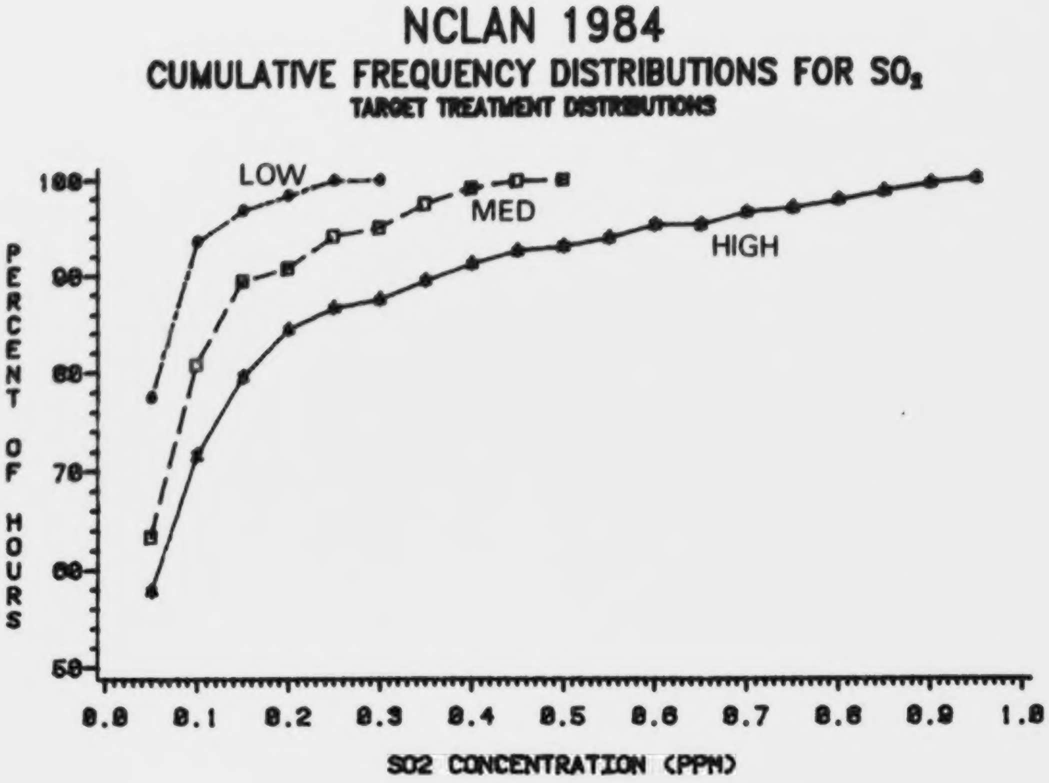

Figure 4.2.1.4. The target cumulative frequency distributions of the hourly SO_2 concentrations in the three treatment exposure regimes.

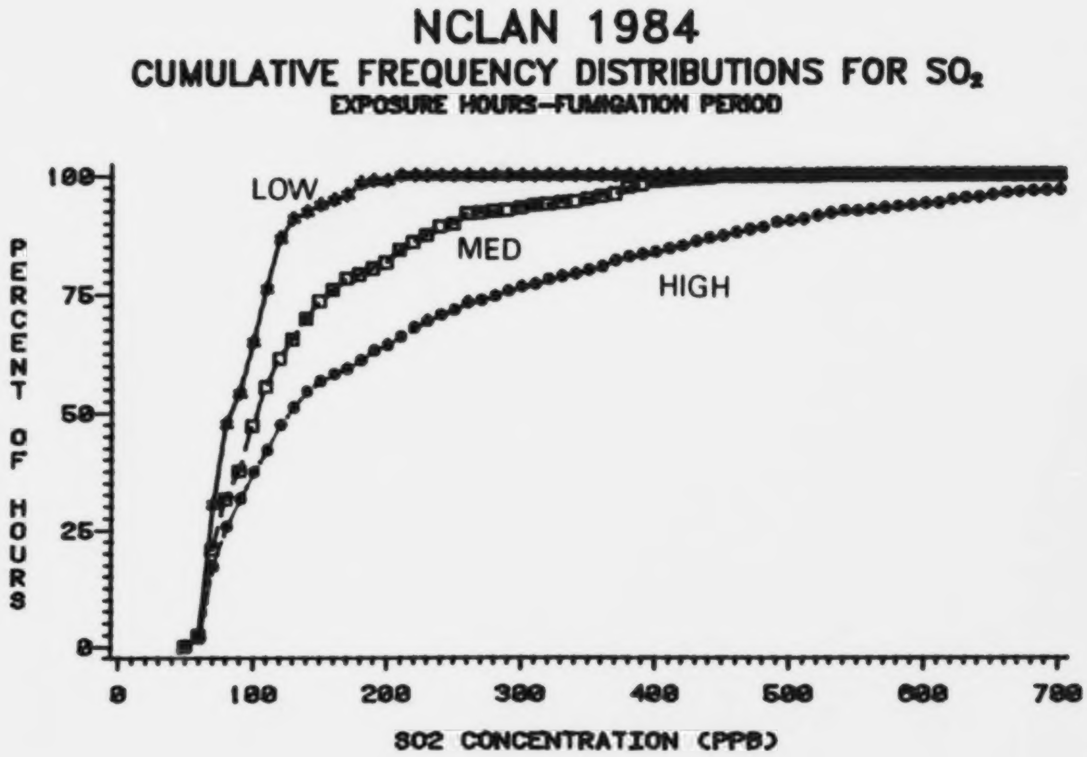

Figure 4.2.1.5. The actual cumulative frequency distributions of the hourly SO_2 concentrations produced by the exposures in the three treatments.

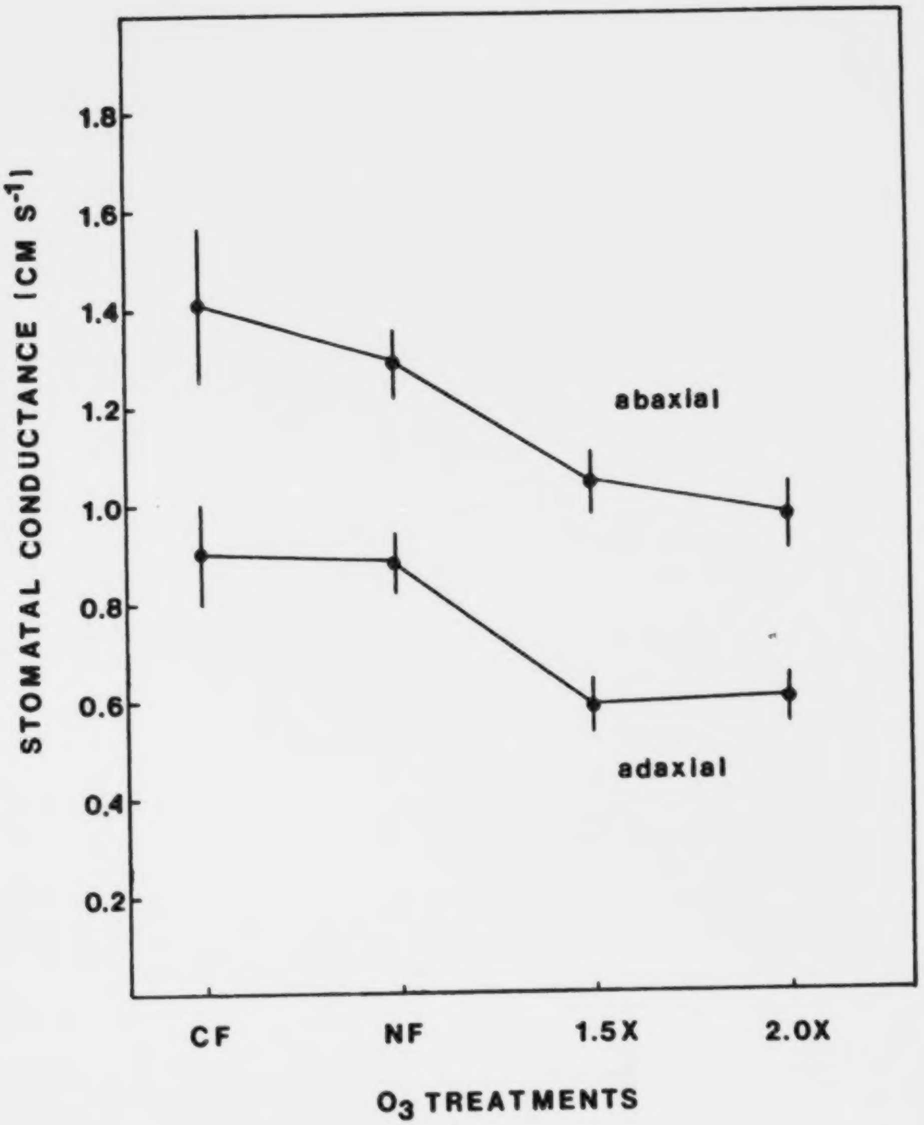

Figure 4.2.1.6. Effect of O_3 on abaxial and adaxial stomatal conductance of red clover. Measurements were taken in SO_2-free chambers from June 30 until August 2. Vertical lines indicate ± standard error.

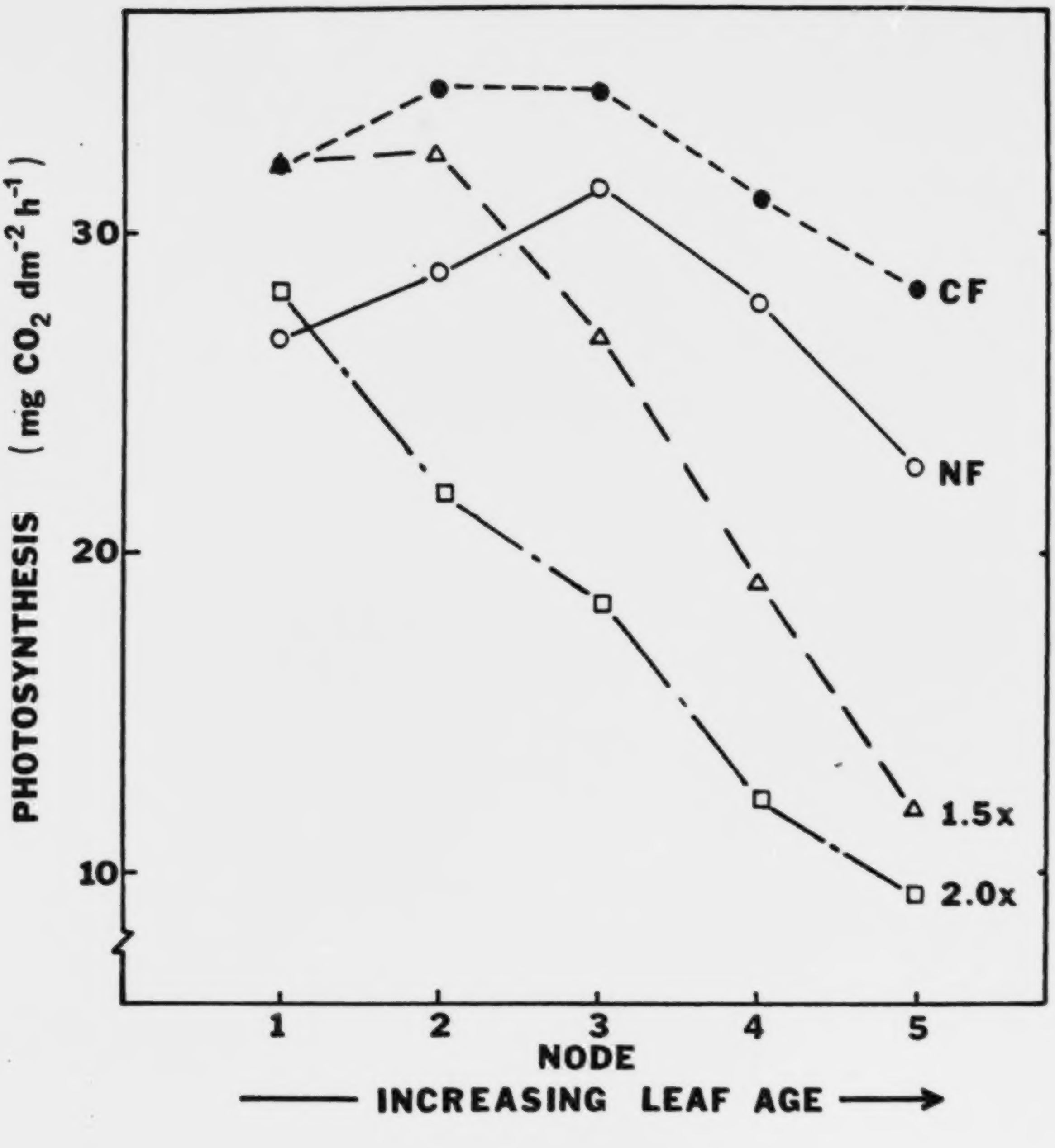

Figure 4.2.1.7. Effects of O_3 and leaf age on photosynthesis of red clover. The measurements were made between July 1 and July 14 on plants in chambers that did not receive SO_2. The number of samples used to calculate the mean for each leaf age per treatment were: CF,12; NF,6; 1.5x,8: and 2.0x,4.

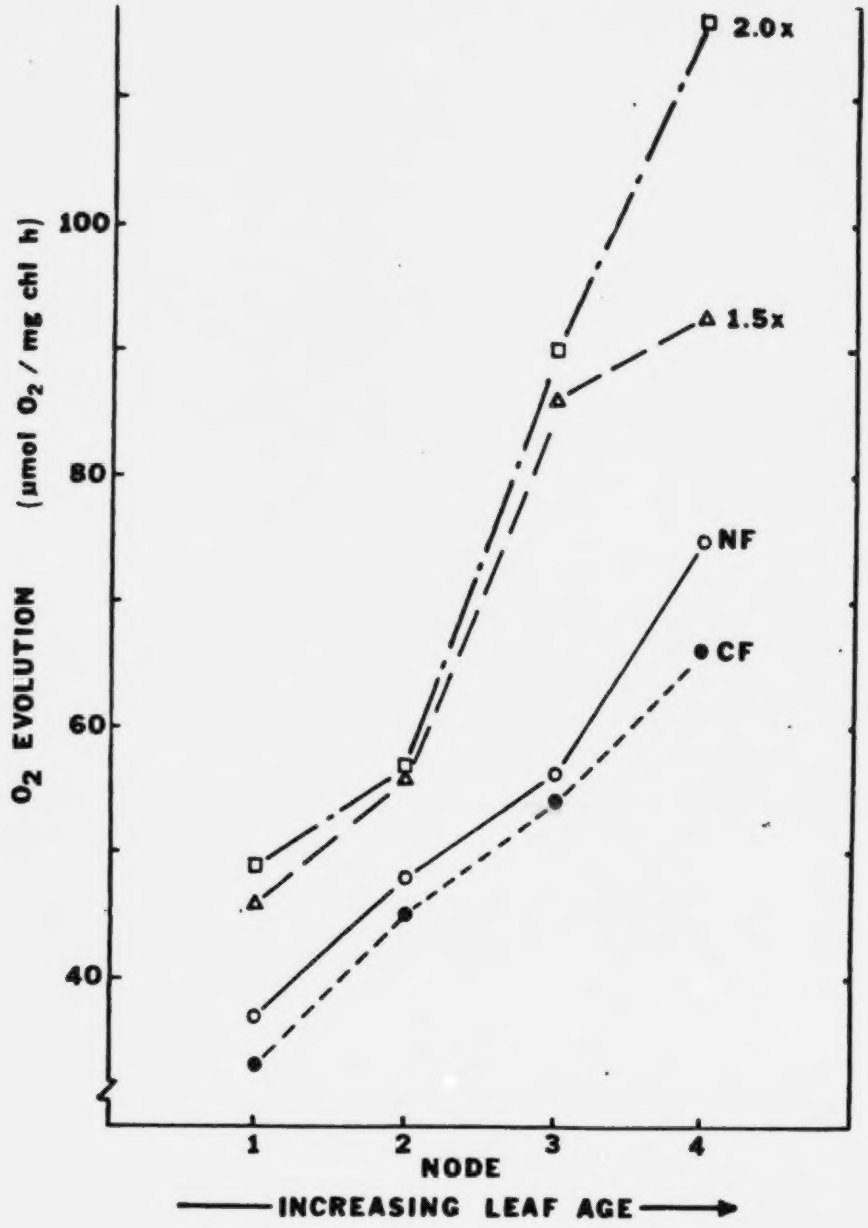

Figure 4.2.1.8. Effect of O_3 on O_2 evolution of red clover. Measurements were made between July 26 and August 10 on plants in chambers that did not receive SO_2. The number of samples taken for each leaf age in each treatment ranged from 5 to 10.

Table 4.2.1.4. Rates of $^{14}CO_2$ fixation, O_2 evolution, and dark respiration as well as the ratio of O_2 evolution to $^{14}CO_2$ fixation, chlorophyll contents, and ratio of chlorophyll a to chlorophyll b in red clover exposed to four different O_3 treatments in open-top chambers in the summer of 1984.

Ozone Treatment (7-h avg ppm)a/	$^{14}CO_2$ Fixation	O_2 Evolution		Ratio of O_2 Evolution to $^{14}CO_2$ Fixation	Chlorophyll	Chlorophyll a / Chlorophyll b	Dark Respiration
	(μmoles CO_2 $dm^{-2}h^{-1}$)	(μmoles O_2 h^{-1} mg chl^{-1})	(μmoles O_2 $dm^{2}h^{1}$)		(μg chl/disk)		(μmoles O_2 consumed/disk/h)
CF (.024)	697.4 [75]b/	.047 [39]	214.0 [39]	.31c/	11.5±.045	2.85±.060 [39]	.217±.011 [26]
NF (.046)	605.1 [48]	.053 [38]	252.6 [38]	.42	12.0±.050	2.70±.059 [36]	.237±.009 [26]
1.5xNF (.057)	526.7 [58]	.070 [32]	228.6 [32]	.43	8.8±.050	2.59±.079 [32]	.222±.010 [22]
2.0xNF (.070)	392.8 [31]	.079 [21]	225.8 [21]	.57	8.0±.080	2.53±.064 [21]	.201±.012 [22]

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a/ ( ) Average concentration monitored from 1000 to 1700 EDT for 58 days of exposure.

b/ [ ] Number of samples.

c/ Average of means.

CO_2 fixed increased with exposure to increasing concentrations of O_3 (Table 4.2.1.4.).

Chlorophyll content. There were no differences in chlorophyll content between the CF and NF treatments but chlorophyll declined dramatically in the 1.5x and 2.0x treatment levels (Table 4.2.1.4., Figure 4.2.1.9.). In addition, the chlorophyll a to b ratio declined from 2.85:1 in the CF treatments to 2.53:1 in the 2.0x treatment level (Table 4.2.1.4).

Effects of SO_2 on Physiology. Stomatal conductance. Measurements of stomatal conductance were taken before and during exposure to SO_2. In general, exposure to the lowest SO_2 regime resulted in stomatal opening whereas exposure to the two highest SO_2 regimes resulted in stomatal closure (Figure 4.2.1.10.). The data presented in Figure 4.2.10. are averaged over all O_3 treatments.

Photosynthesis and respiration. Rates of $^{14}CO_2$ fixation for plants in the SO_2 treatments were assessed only during SO_2 exposures and are shown in Figure 4.2.1.11. Plants exposed to the lowest SO_2 regime tended to have higher rates of $^{14}CO_2$ fixation than plants exposed to comparable levels of O_3 without SO_2. Exposure to SO_2 was found to significantly reduce rates of $^{14}CO_2$ fixation only once in an NF plus high SO_2 treatment. The SO_2 exposure concentration was approximately 0.8 ppm. Plants exposed to the same SO_2 regime in the CF and 1.5x treatment levels were not sampled on the same day as the plants exposed to NF and the high SO_2 regime but were sampled 1 and 9 days later. There was no apparent carryover effect of the high SO_2 exposure in the CF and 1.5x treatment exposed to the high regime.

Chlorophyll content. Plants exposed to the low and medium SO_2 regimes tended to have higher chlorophll contents than plants not exposed to SO_2 (Figure 4.2.1.9.). Plants exposed to the high SO_2 regime had chlorophyll contents similar to those plants not exposed to SO_2.

Dose Response. The total biomass obtained in each treatment from the two harvests is presented in Table 4.2.1.5. The allocation of the harvest biomass between timothy and red clover is presented in Tables 4.2.1.6. and 4.2.1.7, respectively. The data reflect a general lack of effect attributable to SO_2 and a limited decline in biomass attributable to O_3. Analysis of variance confirmed these trends (Table 4.2.1.8.).

Regression analysis was used to develop dose-response functions for the response of the crop to O_3. Since there was no significant SO_2 effect on SO_2 x O_3 interaction, all treatment plots were pooled for the analysis of effects due to O_3. The plot-level yield data were highly variable. The variability created significant problems in the development of dose-response functions. Analyses were conducted using 29 response variables from the harvest data and 23 measures of O_3 treatment. Sets of air quality variables that maximized the correlation coefficient (R^2) were evaluated using all possible regressions. In no cases did R^2 exceed 0.50 without the use of more than four independent variables. Consequently, it was decided to select the most reasonable regression that would predict the total biomass harvested from the plots. The regression incorporates the 12-hr and 7-hr average concentration of

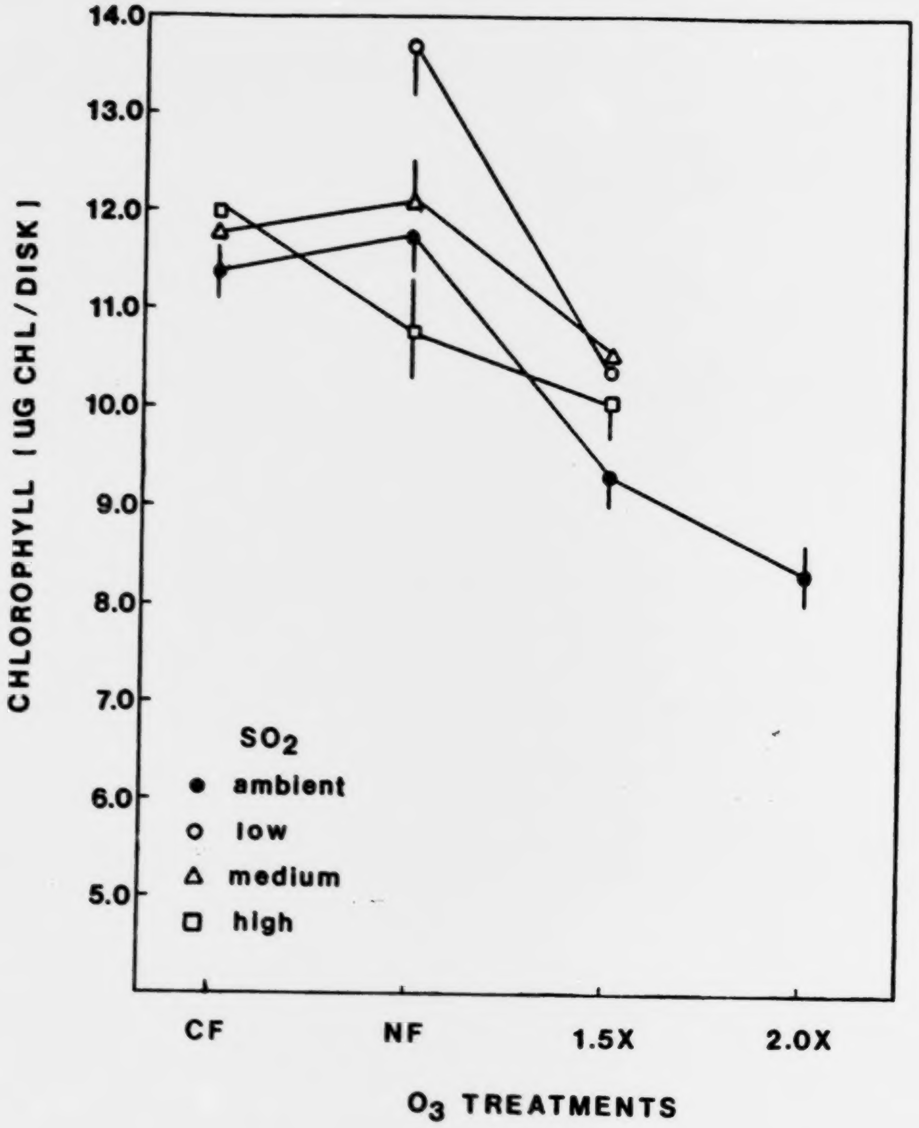

Figure 4.2.1.9. Effects of O_3 and SO_2 on chlorophyll content of red clover. The vertical lines indicate ± a standard error.

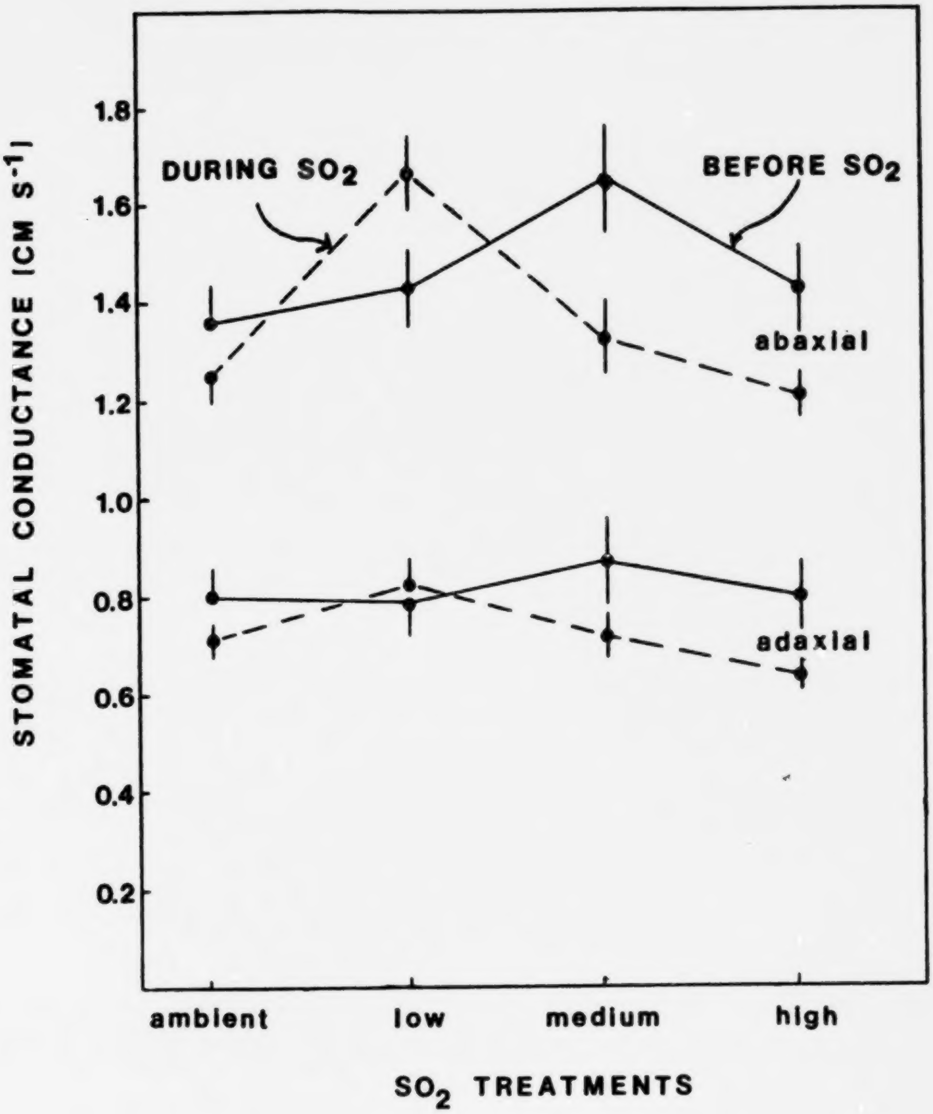

Figure 4.2.1.10. Effect of SO_2 on abaxial and adaxial stomatal conductances of red clover. Solid lines indicate measurements taken within 2 hr of a subsequent SO_2 exposure. Dashed lines indicate measurements taken during SO_2 exposures. Vertical lines indicate ± standard error. Values are averaged over all O_3 treatments.

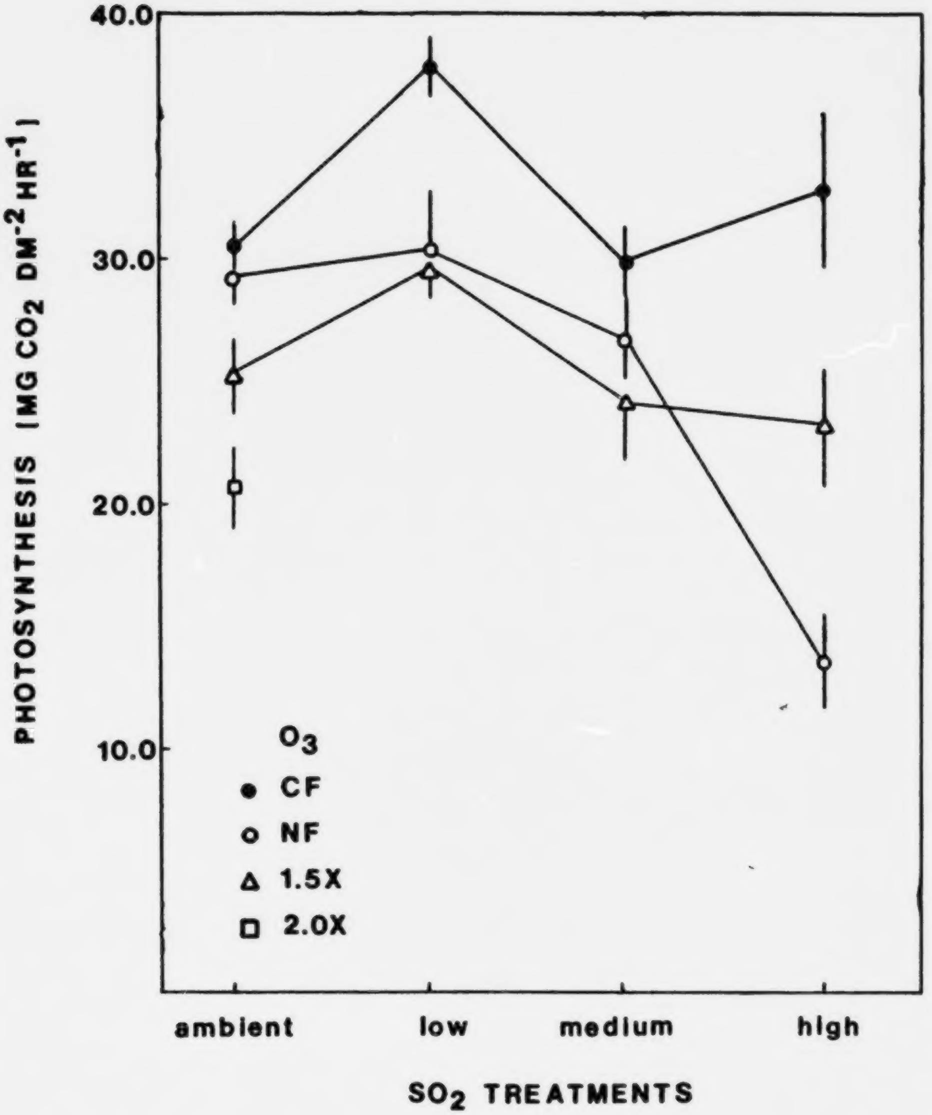

Figure 4.2.1.11. Effects of O_3 and SO_2 on photosynthesis of red clover. The vertical lines indicate ± a standard error.

Table 4.2.1.5. Total biomass of red clover and timothy harvested from open-top chambers in two harvests after pollutant treatments were initiated (yields in kg/ha).

SO_2 Treatment	O_3 Treatment				
	CF	NF	1.5xNF	2.0xNF	Mean
Ambient	3278	3718	2240	2194	2858
Low	4492	4358	2962	2878	3672
Medium	3012	5096	3472	2194	3442
High	4134	3746	2550	2838	3316
Mean	3730	4230	2806	2526	

Table 4.2.1.6. Total biomass of timothy harvested from open-top chambers in two harvests after pollutant treatments were initiated (yields in kg/ha).

SO_2 Treatment	O_3 Treatment				
	CF	NF	1.5xNF	2.0xNF	Mean
Ambient	1484	774	572	564	848
Low	538	794	894	1240	866
Medium	278	320	200	1138	484
High	178	454	718	588	484
Mean	620	586	596	882	

Table 4.2.1.7. Total biomass of red clover harvested from open-top chambers in two harvests after pollutant treatments were initiated (yield in kg/ha).

SO_2 Treatment	O_3 Treatment				
	CF	NF	1.5xNF	2.0xNF	Mean
Ambient	1794	2944	1668	1630	2010
Low	3954	3564	2068	1638	2806
Medium	2734	4776	3272	1056	2958
High	3956	3292	1832	2250	2832
Mean	3110	3644	2210	1644	

Table 4.2.1.8. Analysis of variance for the effects of O_3 and SO_2 on the yield (gm/plot) of red clover and timothy in the study conducted in Ithaca, NY in 1984.

Source of Variation	df	Sum of Squares	Mean Square	F	Significance
O_3	3	99197.9	33065.9	4.50	$P<0.05$
SO_2	3	23811.1	7937.0	1.08	NS
Block	1	68501.9	68501.9	9.32	$P<0.01$
$O_3 \times SO_2$	9	28596.9	3177.4	0.43	NS
Error	15	110192.8	7346.2		

O_3 and the proportion of clover in the plot prior to the initiation of the treatments. Although the regression is highly significant and has an R^2 of 0.55, it may not be readily used as a dose-response function in NCLAN since it incorporates a variable other than the ambient O_3 concentration. The linear dose-response function is presented in Table 4.2.1.9.

Dose-response functions were also produced using the Weibull model and the 7-hr and 12-hr average concentrations of O_3. The functions are presented in Table 4.2.1.8. In some instances, the confidence intervals for the c parameter are quite broad. The Weibull dose-response functions for both the 7-hr and 12-hr average O_3 concentrations are presented in Table 4.2.1.9.

Samples of timothy and red clover from the pretreatment and the two treatment harvests received nutrient and mineral analysis. Variables evaluated included crude protein, available protein, acid detergent fiber, total digestible nutrients, estimated net energy, calcium, phosphorus, magnesium, potassium, sodium, iron, zinc, copper, manganese, and sulfur. None of the measures of nutritional value in either red clover or timothy were affected by the pollutant treatments. The concentrations of elements in the plants were unchanged except for sulfur which exhibited a minor increase with increasing SO_2 treatment levels.

Table 4.2.1.9. Linear and Weibull regression equations for total red clover and timothy forage yield at Ithaca, NY in 1984 (yields are kg/ha).

Linear

$$\text{Yield} = 3267.37 + 920.69\,(O_312) - 829.72\,(O_37) + (3272.12 \times CL)$$

Where: O_312 is the 12-h average O_3 concentration

O_37 is the 7-h average O_3 concentration

CL is the proportion, by weight, of clover in the initial stand

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$$\text{Yield} = 4119.19 \exp - (O_312/0.072)^{4.034}$$

Where: O_312 is the 12-h average O_3 concentration

$$\text{Yield} = 4140.33 \exp - (O_37/0.083)^{3.882}$$

Where: O_37 is the 7-hr average O_3 concentration

4.2.2. Impact of O_3 and SO_2 on Alfalfa (CSRCLAP)--L. Kress, H.J. Smith, and J.E. Miller

4.2.2.1. Introduction

Alfalfa (Medicago sativa L.) is probably the world's most important forage crop. In the U.S., alfalfa and other forage crops are the fourth leading cash crop (as hay). Lack of information on the sensitivity of forage crops to O_3 was seen as a major deficiency of the NCLAN economic loss assessment. Thus, the Central States project was designed to examine the effects of O_3 and SO_2 on the yield of alfalfa. The specific objectives were to: 1) determine the exposure-response relationship between daily O_3 exposure and yield of alfalfa; 2) determine the exposure-response relationship between simulated point source SO_2 exposure and yield of alfalfa; and, 3) evaluate the potential interaction of intermittent SO_2 exposure and daily O_3 exposure on yield of alfalfa.

4.2.2.2. Materials and methods

Many of the important events concerning this experiment have been listed in Table 4.2.2.1. Seed of alfalfa, 'WL-312,' was broadcast at a rate of 27 kg/ha on 31 August 1983. An unusually severe winter with frequent freezing and thawing caused considerable frost heaving of the plants and necessitated reseeding the alfalfa on 17 May 1984. Due to apparent unequal germination and variability in initial stand densities, the alfalfa was allowed to develop untreated in the ambient air until the first harvest (taken 30 July - 5 August at 10% flowering). Forty-two plots (3 m diam) were selected for uniform stand density 29 June. The center m^2 of each plot was used to measure yield.

The soil was a Morley silt loam (fine, illitic, mesic Typic Hapludalf) upland timber soil, with a high water-holding capacity and low permeability. No fertilizer was used in August 1983 since soil tests showed 18 kg P/ha (54-57 kg/ha recommended) and 424 kg k/ha (282-305 kg/ha recommended). Tests revealed P and K levels were still above recommended levels in April 1984. Total rainfall (May - September, 1984) was near average (44.7 cm), but was 79% lower than the average for June - August (19.5 cm). Although no wilting of alfalfa plants was apparent (as was noted in the drought-stressed plants at the SWRCLAP site [section 4.1.3.]), all plots were irrigated with an additional 1 cm in June and 2.54 cm in August.

The experimental design was randomized complete block with two replications of a five O_3 x four SO_2 pattern. The O_3 treatments were CF, NF, 1.5 NF, 2.0 NF, and 2.5 NF. The SO_2 treatments were zero, low frequency distribution, medium frequency distribution, and high frequency distribution. The SO_2 treatments differed not only in the hourly concentrations, but also in the total hours of exposure. There was also a non-chambered plot in each replication. The open-top chambers were established over the plots on 6 August and O_3 exposures began on 8 August. Ozone was added whenever the ambient O_3 was above 0.03 ppm between 0800-2000 CDT, in the absence of rain (Table 4.2.2.2). The SO_2 exposures began on 14 August and generally lasted 1-6 hours on 3-day/wk,

Table 4.2.2.1. Chronology of important events during the 1984 study to determine the impact of O_3 and SO_2 on the yield of alfalfa at CSRCLAP.

April		Decision was made that the fall planted alfalfa plots had sustained enough winter damage (primarily frost heaving) to preclude their use in the study.
May	10-16	Field rototilled and six spot soil tests run in preparation for replanting alfalfa.
	17	Planted WL-312 alfalfa seed by broadcast seeder at the rate of 28-34 Kg/ha and rolled field by hand with a sod roller.
	19	1.68 cm rain
	22	Alfalfa germinating
	22-23	4.70 cm rain
	24-25	1.20 cm rain
	26	1.63 cm rain
	28	0.08 cm rain
	29	2.75 cm rain
	30	Trace rain
June	5	Trace rain
	7	0.30 cm rain
	9	0.66 cm rain
	12-13	Watered with lawn sprinkler - 1.0 cm
	14	1.14 cm rain
	14-19	Calibrate sample lines 1-42 @ 0.20 ppm O_3
	16	0.25 cm rain
	20	Watered plot lightly in preparation for herbicide spraying.
	21	Sprayed alfalfa with POAST (grass killer) and crop oil (0.55% solution of each in water) at a rate of 324 liters/ha to remove residual wheat and other grasses.
	21-22	1.19 cm rain

Table 4.2.2.1. Continued.

	24-25	2.92 cm rain
June	26	0.20 cm rain
	29	2 blocks of 21 plots each selected for study
July	2	Chamber frames placed over 20 plots/block
	2-13	Hand weeded plots. ZP Rodent Bait (2% zinc phosphide) placed randomly around field
	3	0.51 cm rain
	5	0.71 cm rain
	9	0.05 cm rain
	10-11	1.52 cm rain
	15	0.03 cm rain
	20	0.03 cm rain
	24	3.43 cm rain
	25	Trace rain
	26	0.76 cm rain
	30-31	NCLAN instrument audit. Began pre-fumigation harvest
August	1-5	Pre-fumigation harvest -1 m^2 from each plot
	3	0.56 cm rain
	4	0.51 cm rain
	6	Chamber panels on - fans operating
	7	0.05 cm rain
	8	Ozone exposures begin
	9	Watered each plot in Block "A" - 1.27 cm
	9-10	4.45 cm rain
	14	Sulfur dioxide exposures begin
	15	Watered each plot in Block "B" - 0.64 cm

Table 4.2.2.1. Continued.

August	16	Injury noted in 2.0 NF and 2.5 NF O_3 treatments - whitish and tan stipple and bifacial necrosis.
	17	0.08 cm rain - no O_3 exposures.
	23	No O_3 exposures - concentration < 0.03 ppm. Watered each plot in Block "B" - 0.64 cm.
	24	Watered each plot in Block "A" - 0.64 cm.
	27	0.05 cm rain
	28	Watered each plot in Block "B" - 0.64 cm.
	29	Watered each plot in Block "A" - 064 cm.
	31	Watered each plot in Block "B" - 0.64 cm. 0.13 cm rain.
September	1	1.70 cm rain.
	2	0.08 cm rain. No O_3 exposures 1600-2000.
	3	No O_3 exposures - concentration < 0.03 ppm.
	4	0.03 cm rain. No O_3 exposures 1600-2000.
	7	No O_3 exposures 1600-2000 - high winds.
	8	1.02 cm rain. No O_3 exposures 1600-2000.
	9	0.03 cm rain. Rodenticide randomly applied in plots.
	10	0.13 cm rain.
	13	No O_3 exposures - low O_3 and 0.76 cm rain.
	14	No O_3 exposures - low O_3.
	15	No O_3 exposures - low O_3 - 0.20 cm rain.
	22	No O_3 exposures 1600-2000 - 1.23 cm rain.
	23	No O_3 exposures - low O_3 and 0.63 cm rain.
	24	No SO_2 exposures - plants wet.
	25	No O_3 or SO_2 exposures - low O_3 and 7.28 cm rain.
	26	No O_3 exposures - low O_3.

Table 4.2.2.1. Continued.

September	27	No O_3 exposures - low O_3
	28	0.08 cm rain. Fans left on this night to prevent frost.
	29	Last fumigations. Fans left on this night to prevent frost.
	30	Foliar injury evaluations. Fans left on this night to prevent frost.
October	1	Block "A" panels removed; collected soil cores for rhizosphere evaluation.
	2-3	Harvested 1 m^2 from Block "A" plots.
	3	Block "B" panels removed; collected soil cores for rhizosphere evaluation.
	3-4	Harvested 1 m^2 from Block "B" plots.
	6-31	6.90 cm rain
	7-12	Calibrated sampling lines.
November	28	Rodenticide applied under each fan box.
	29	Soil samples collected for pH, OM, P, K analysis.

Table 4.2.2.2. 1984 O_3 Exposures - 53 Days, Argonne, IL.[a]

Date	Time	Length (h)	Date	Time	Length (h)
8/8	10:15-12:40/14:20-20:00	8.05	9/4	13:25-16:00 (RAIN)	2.35
9	11:00-19:00	8.0	5	12:00-17:15	5.05
10	11:10-19:35	8.25	6	10:00-20:00	10.0
11	09:35-20:00	10.25	7	08:00-16:00 (too windy)	8.0
12	11:00-19:00	8.0	8	08:30-16:00 (RAIN)	7.3
13	11:00-20:00	9.0	9	11:45-18:35	6.5
14	10:15-20:00	9.45	10	11:15-16:00	4.45
15	10:25-20:00	9.35	11	10:55-18:45	7.5
16	08:45-20:00	11.15	12	09:15-20:00	10.45
17	RAIN	0	13	low O_3 and RAIN	0
18	09:45-20:00	10.15	14	low O_3	0
19	11:45-19:45	8.0	15	low O_3	0
20	11:00-20:00	9.0	16	11:00-17:40	6.4
21	09:15-20:00	10.45	17	11:00-20:00	9.0
22	10:00-20:00	10.0	18	10:15-20:00	9.45
23	low O_3	0	19	10:40-20:00	9.2
24	11:00-19:15	8.15	20	08:45-17:15	8.3
25	08:45-20:00	11.15	21	11:40-20:00	8.2
26	10:00-20:00	10.0	22	08:00-16:00 (RAIN)	8.0
27	08:00-20:00	12.0	23	low O_3 and RAIN	0
28	09:45-20:00	10.2	24	14:30-19:15	4.45
29	10:45-20:00	9.15	25	low O_3 and RAIN	0
30	09:45-19:35	9.5	26	low O_3	0
31	10:45-20:00	9.15	27	low O_3	0
9/1	09:00-20:00	11.0	28	13:15-15:30	2.15
2	08:00-16:00 (RAIN)	8.0	29	13:30-16:30	3.0
3	low O_3	0			

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[a] Average starting time 1025 hr; average stopping time 1855 hr; average length of exposure 8.5 hr; days with 10 or more hr of added O_3 = 12; days with no added O_3 = 10

depending on a frequency distribution developed from TVA monitoring data (Bob Kohut, personal communication; Table 4.2.2.3). Exposures were terminated 29 September following three consecutive nights of frost. One m^2 was harvested to a 7-cm height from the middle of each plot on 3-4 October.

Methods for pollutant dispensing and monitoring followed basic NCLAN procedures as described in previous NCLAN reports and numerous publications (19-21). Each plot was monitored for 2 minutes once every 20 or 22 minutes. Sampling system and sampling line O_3 losses varied from 11 to 19% (but were stable for individual lines), and the recorded O_3 values for each plot were adjusted accordingly. System losses for SO_2 were essentially zero. Ambient O_3 and SO_2 were monitored continuously, at 3-m from ground.

Foliar injury (as a subjective estimate of the overall percentage of chlorosis, necrosis, stipple, and leaf rust) was estimated in the central 1 m^2 area of each plot from one replication on 30 September. Four 0.25 m^2 quadrants were harvested in each plot. Plant tissue was placed in paper bags, oven dried to < 1% moisture content, and weighed. Tissue samples were sent to EPA, Corvallis, OR, for quality analysis (reducing sugar, sucrose, starch). Four 2.5 x 15 cm soil cores were taken in October from 28 of the 42 plots for an evaluation of the root biomass, and the rhizosphere microorganisms associated with alfalfa. Soil samples also were collected from each plot and sent to the Soil and Plant Analysis Laboratory, University of Wisconsin, for analysis of pH, organic matter, and available P and K.

The data were analyzed by a factorial analysis of variance or covariance. The sources of variation were replication, O_3 treatment, SO_2 treatment, O_3 x SO_2 interaction, and residual (Error a). The covariates used were the pre-treatment harvest weight and the individual soil variables of pH, organic matter, P, and K. Linear and quadratic models also were generated using the SAS GLM procedure. Weibull models were not fit because of the lack of response to the pollutants.

4.2.2.3. Results

Pollutant concentrations. The mean seasonal O_3 concentrations (12-h/day means) from 8 August to 29 September (including non-exposure hours) for the AA, CF, NF, 1.5 NF, 2.0 NF, and 2.5 NF treatments were 0.042, 0.018, 0.039, 0.053, 0.067, and 0.083 ppm, respectively (Table 4.2.2.4). The seasonal 7-h/day and 1-h/day means were 11-22% and 42-66% higher, respectively, than the 12-h/day means. High and second high values for each mean have also been provided. The NAAQS of 0.012 ppm for 1 hour was violated in all three above-ambient treatments.

The daily 1-h, 7-h, 12-h, and 24-h mean ambient O_3 concentrations (measured at 3 m height) between 1 June and 30 September 1984 are shown in Figure 4.2.2.1. The highest daily values were 0.139 ppm (21 July), 0.110 ppm (21 July), 0.095 ppm (21 July), and 0.062 ppm (7 September) for the 1-h, 7-h, 12-h, and 24-h values, respectively. The mean seasonal hourly

Table 4.2.2.3. Frequency of hourly mean SO_2 concentrations for the high, medium, and low exposure regimes in the 1984 CSRCLAP alfalfa studies, 9 Aug - 29 Sept.

Concentration (ppm)	Number of Hours[a]		
	High	Medium	Low
0	216 (1152)[b]	260 (1196)	285 (1221)
0.05	54	31	20
0.10	15	9	4
0.15	7	3	1
0.20	5	2	1
0.25	2	2	1
0.30	3	4	
0.35	1		
0.40	1		
0.45	1	1	
0.50	1		
0.55	1		
0.60	1		
0.65	1		
0.80	2		
0.85	1		

[a] Total number of hours for a six hour period (approximately 1000-1600) daily between 9 Aug and 29 Sept.

[b] Total hours including the remaining 18 hours for each day.

Table 4.2.2.4. Highest and second highest 1-hr (between 0700 and 1900 CST), 7-h (0900 to 1600 CST), and 12-h (0700 to 1900 CST) mean O_3 values, and the seasonal 1-h peak, 7-h, and 12-h mean values for each treatment, 8 August - 29 September 1984.

	12-h/day Values (ppm)			7-hr/day Values (ppm)			1-hr/day Values (ppm)		
Treatment	Seasonal[a] Mean	Highest[b]	2nd Highest[b]	Seasonal Mean	Highest	2nd Highest	Seasonal Mean	Highest	2nd Highest
AA	0.042	0.073	0.072	0.048	0.082	0.080	0.060	0.105	0.100
CF	0.018	0.051	0.039	0.022	0.060	0.047	0.030	0.079	0.070
NF	0.039	0.073	0.071	0.044	0.079	0.077	0.056	0.105	0.101
1.5 NF	0.053	0.133	0.099	0.059	0.118	0.105	0.080	0.175	0.158
2.0 NF	0.067	0.140	0.127	0.075	0.145	0.143	0.106	0.230	0.218
2.5 NF	0.083	0.183	0.154	0.094	0.195	0.167	0.134	0.276	0.270

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[a] Each seasonal mean value for the chambered plots is derived from average of 20-24 2-minute samples per hour (8 plots/treatment).

[b] Highest or second highest value in one of the eight plots of each treatment.

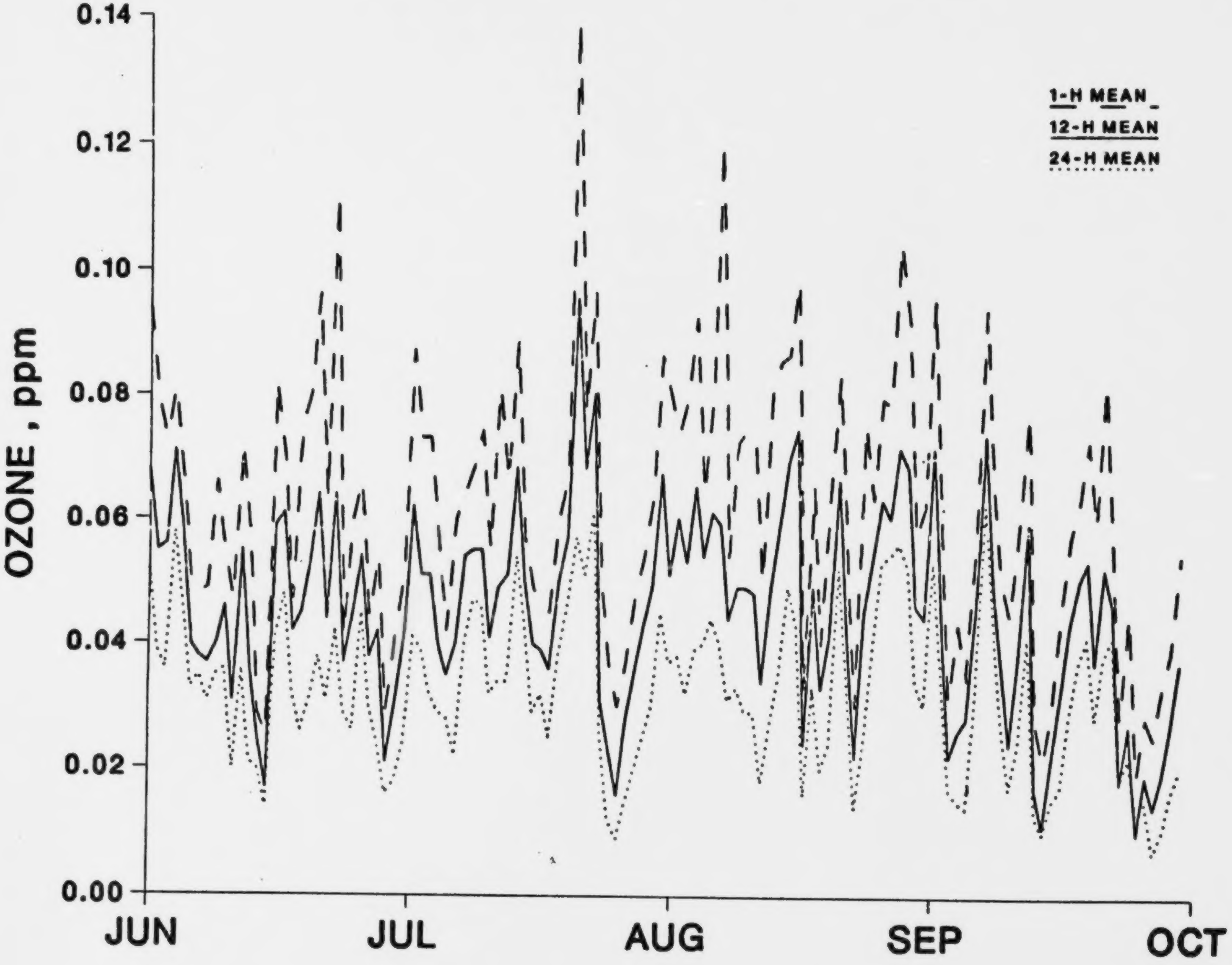

Figure 4.2.2.1. Daily 1-h (maximum), 7-h (0900-1600 CST), 12-h (0700-1900 CST), and 24-hr- O_3 concentrations from 1 June to 31 September 1984, at Argonne, IL, measured at a 3 meter height. Experimental treatments on alfalfa were from 8 August to 29 September.

average diurnal fluctuations in O_3 concentrations for all treatments are shown in Figure 4.2.2.2.

The SO_2 treatment regimes are shown in Table 4.2.2.3. The total doses were 2.0, 5.45, and 13.60 ppm-h for the low, medium, and high treatments, respectively. Ambient SO_2 was detected (detection limit 0.005 ppm) in 27% of the total hours between 22 June and 30 September 1984. The highest 24-h mean, 3-h mean, 1-h mean, and instantaneous peak values were 0.013 ppm, 0.068 ppm, 0.105 ppm, and 0.130 ppm, respectively. The seasonal mean SO_2 values were 0.003 ppm (24-h), 0.012 ppm (3-h peak), and 0.17 ppm (1-h peak). Forty-three and 46% of the daily peak 1-h and 3-h values, respectively, occurred between 0700-1900 CST while 22% and 32%, respectively, occurred during the NCLAN 7-h addition period (0900-1600 CST). The SO_2 values reported for the treatments in Table 4.2.2.3 were inclusive of the ambient readings.

Foliar injury. The percentage of the foliage affected by leaf rust (Uromyces striatus) varied from 33 to 81, but did not appear to be related to either O_3 or SO_2 treatment (Table 4.2.2.5). The percentage of chlorotic leaves was significantly ($p = 0.05$) greater in the 2.5 NF treatment than all other treatments (according to the Duncans New Multiple Range Test). The percentage of necrotic tissue was not affected by O_3 treatment, and neither chlorosis nor necrosis were affected by SO_2 treatment.

Yield and Quality. The yield and quality data are presented in Table 4.2.2.6. The analysis of variance of the chambered plot data indicated only a significant ($p = 0.05$) SO_2 effect on final dry weight. However, the analysis of covariance (covariate of pre-treatment harvest weight or the individual soil variables) indicated no O_3, SO_2 or $O_3 \times SO_2$ effects on the yield or quality measures. Linear and quadratic regressions were likewise not significant for any of the yield or quality measures. A T-test indicated a significant difference between the NF chamber plots and the AA plots only for leaf reducing sugar content.

Root and rhizosphere. The data for number of mycorrhizal fungus spores, percent root colonization, root length, nodule number, nodule weight, and number of nematodes are presented in Table 4.2.2.7. The analysis of variance indicated no significant treatment effects for any of the measured variables. An analysis of covariance (covariates PH, OM, P, and K) indicated only a significant ($P = 0.05$) effect of O_3 treatment on fungal spore number (P was the significant soil covariate). Linear and quadratic regressions were not significant for any of the measured variables. A T-test also indicated no significant difference between the NF chamber plots and the AA plots for any of the variables.

4.2.2.4. Discussion

There were no indications of either O_3 or SO_2 effects on the yield and quality of alfalfa. Several factors may have contributed to the apparent lack of sensitivity of alfalfa. First, the cultivar, 'WL-312,' may not be sensitive (the authors hesitate to draw that conclusion from the data presented). Second, the site for the study was not a good one for

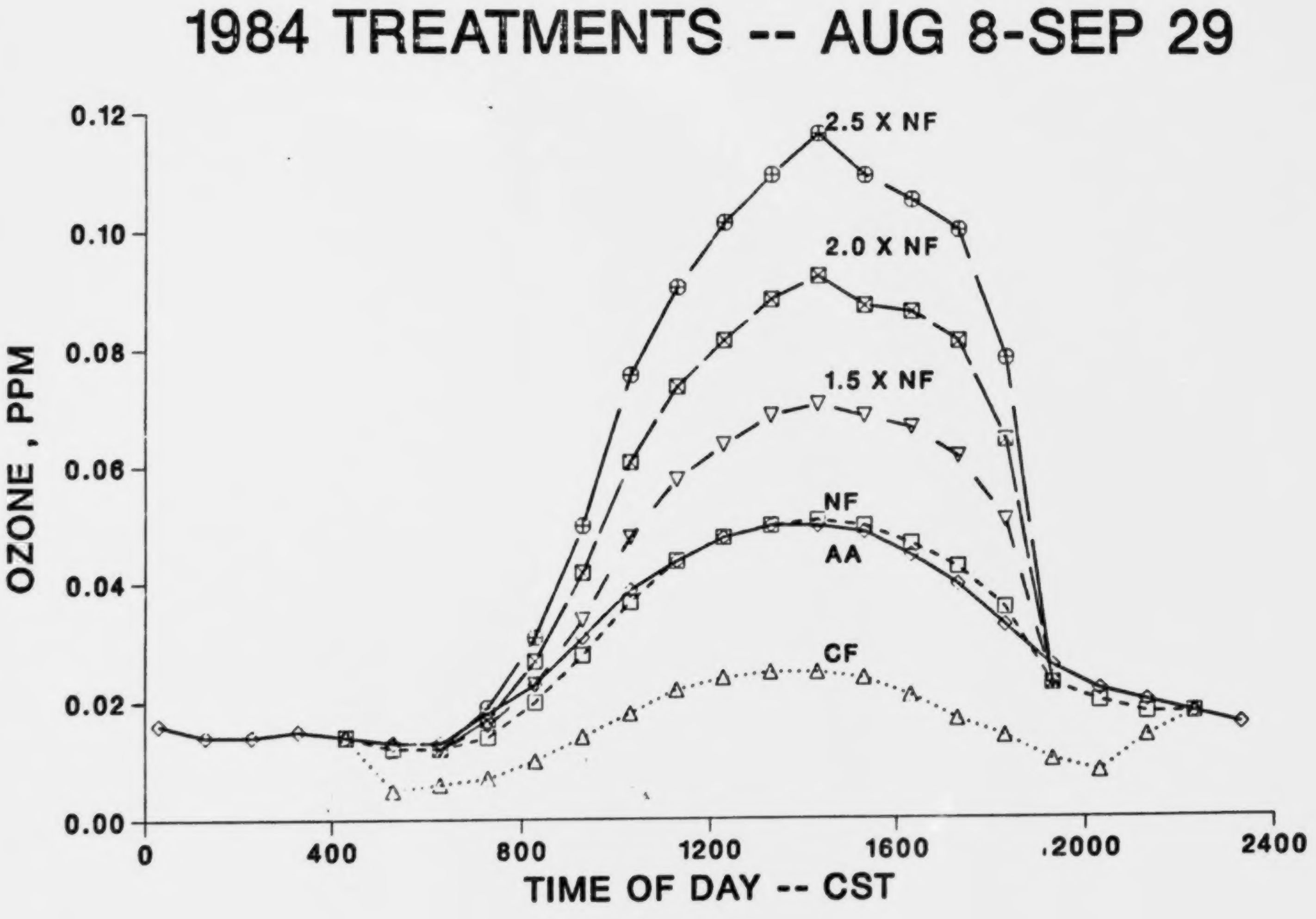

Figure 4.2.2.2. Mean seasonal hourly average diurnal fluctuations in O_3 concentration for all treatments from 8 August to 29 September 1984.

Table 4.2.2.5. Amount of leaf rust and foliar injury on alfalfa exposed to O_3 and/or SO_2 in open-top chambers from 8 August to 29 September 1984.

	% of Canopy Exhibiting[b]				% of Canopy Exhibiting[b]		
O_3 Concentration[a] (ppm/Treatment)	Rust	Chlorosis	Stipple and Necrosis	SO_2 Concentration[c] (ppm-h/Treatment)	Rust	Chlorosis	Stipple and Necrosis
0.042/(AA)	50	10	30	0	50	10	30
0.018/(CF)	33	16	21	0	51	24	28
0.039/(NF)	55	10	25	2.00/(low)	54	13	28
0.053/(1.5 NF)	81	15	35	5.45/(medium)	54	17	21
0.067/(2.0 NF)	53	16	14	13.60/(high)	56	20	18
0.083/(2.5 NF)	48	35	24				

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[a] Seasonal (53 days) 12-h/day O_3 concentration (0800-2000 CDT). On 43 days when O_3 was actually dispensed, the average start/stop times were 1025/1855 CDT.

[b] Chamber treatments are averaged over the four SO_2 treatments for O_3, and over the five O_3 treatments for SO_2. The AA treatment is a single plot value.

[c] Sulfur dioxide treatments were 3-d/wk for a total of 27-h, 51-h, and 96-h in the low, medium, and high treatments, respectively.

Table 4.2.2.6. Top dry weight, pre-treatment top dry weight, and leaf and stem reducing sugar, sucrose, and starch levels for alfalfa exposed to O_3 and/or SO_2 in open-top chambers from 8 August to 29 September, 1984.

O_3 Concentration[a] (ppm/treatment)	Top Dry Weight[b] (g/m^2)	Pre-treatment Dry Weight (g/m^2)	Leaf			Stem		
			Reducing Sugar	Sucrose	Starch	Reducing Sugar	Sucrose	Starch
			(μmol/g dry wt)			(μmol/g dry wt)		
0.042/(AA)	120(17)	210(20)	126(9)	66(27)	236(34)	75(1)	80(9)	205(18)
0.018/(CF)	142(18)	240(55)	161(1)	107(4)	359(95)	88(27)	124(29)	286(20)
0.039/(NF)	139(20)	217(55)	191(8)	78(29)	320(47)	71(1)	98(31)	274(51)
0.053/(1.5NF)	147(25)	239(44)	183(4)	84(9)	273(43)	105(26)	88(2)	240(29)
0.067/(2.0NF)	133(12)	241(55)	175(12)	92(8)	313(14)	99(43)	108(20)	271(75)
0.083/(2.5NF)	149(21)	240(39)	196(21)	79(30)	296(122)	82(22)	86(26)	247(98)
SO_2 Concentration[c] (ppm-h/treatment)								
0/(AA)	120(17)	210(20)						
0/(NF)	148(19)	252(60)						
2.00/(low)	131(20)	223(31)						
5.45/(medium)	137(16)	219(44)						
13.60/(high)	151(19)	247(52)						

[a] Seasonal (53 days) 12-h/day O_3 concentration (0800-2000 CDT). On 43 days when O_3 was actually dispensed, the average start/stop times were 1025/1855 CDT.

[b] Chamber treatment values for foliage weight were averaged over two replications of four SO_2 treatments for O_3, and over two replications of five O_3 treatments for SO_2. The AA treatment value was averaged over two replications. Values in parentheses are standard deviations. The foliage quality measures are for the two replicaitons of the O_3 (alone) treatment.

[c] Sulfur dioxide treatments were 3 d/wk for a total of 27-h, 51-h, and 96-h in the low, medium, and high treatments, respectively.

Table 4.2.2.7. Total number of mycorrhizal fungus spores (Fun), total number of nematodes (Nem), root length, percent of root length colonized by mycorrhizal fungi (% colon), root nodule number (Nod #), and root nodule weight (Nod wt) for alfalfa exposed to O_3 and/or SO_2 in open-top chambers from 8 August to 29 September, 1984.

O_3 Concentration[a] (ppm/treatment)	Fun[b] (#/g soil)	Nem (#/g soil)	Root Length (cm/g soil)	% Colon	Nod Wt (mg)	Nod (#/g soil)
0.042/(AA)	0.78 (.12)	1.07 (.36)	324 (204)	18.3 (0.9)	0.20 (0.16)	6.7 (5.4)
0.018/(CF)	0.46 (.11)	1.03 (.22)	376 (119)	16.5 (3.2)	0.23 (0.19)	7.6 (2.5)
0.039/(NF)	0.55 (.19)	1.11 (.66)	347 (86)	16.9 (2.3)	0.18 (0.11)	6.5 (2.6)
0.053/(1.5NF)	0.54 (.14)	1.46 (.12)	377 (111)	15.7 (1.1)	0.23 (0.13)	6.2 (2.6)
0.067/(2.0NF)	0.39 (.07)	1.45 (.48)	315 (63)	16.9 (4.0)	0.17 (0.04)	6.0 (2.1)
0.083/(2.5NF)	0.60 (.19)	1.57 (.94)	334 (104)	16.9 (3.8)	0.14 (0.06)	7.1 (3.0)
SO_2 Concentration[c] (ppm-h)/treatment)						
0/(AA)	0.78 (.12)	1.07 (.36)	324 (204)	18.3 (0.9)	0.20 (0.16)	6.7 (5.4)
0/(NF)	0.46 (.10)	1.21 (.40)	324 (114)	16.2 (3.7)	0.21 (0.13)	7.0 (2.9)
2.00/(low)	0.51 (.20)	1.09 (.55)	406 (81)	18.5 (1.7)	0.24 (0.22)	7.3 (2.8)
5.45/(medium)	0.51 (.15)	1.56 (.79)	358 (107)	16.1 (3.2)	0.16 (0.04)	5.7 (1.8)
13.60 (high)	0.53 (.22)	1.31 (.70)	340 (43)	16.9 (3.1)	0.13 (0.05)	7.4 (1.7)

[a] Seasonal (53 days) 12-h/day O_3 concentration (0800-2000 CDT); on 43 days when O_3 was actually dispensed, the average start/stop times were 1025/1855 CDT.

[b] Soil cores were not taken in all plots; the N values for the O_3 treatments range from 2 to 8, and for SO_2 from 4 to 10.

[c] Sulfur dioxide treatments were 3 d/wk for a total of 27-h, 51-h, and 96-h in the low, mediume, and high treatments, respectively.

alfalfa; the soil was shallow and poorly drained, and the plants remained shallow rooted (15-20 cm). Third, this was the establishment year for a spring-planted crop. Fourth, the early and middle parts of the season were very dry, probably resulting in restricted root development and therefore top growth. The alfalfa study at the SWRCLAP site (Section 4.1.3.) did not note significant O_3 effects on yield until the fourth harvest, from drought-stressed plots; we only had one harvest following O_3 treatments. Fifth, the O_3 concentrations were relatively low during the treatment period and, in fact, were below 0.03 ppm on nearly 20% of the treatment days. Finally, the leaf rust infection [(for which there is no effective control (22)] placed the plants under almost continuous stress and in most plots removed upwards of 50% of the foliar surface from apparently active production.

A positive result of this study was the identification of a possible relationship between pollutant levels and nematode population dynamics in the rhizosphere. There was an increase in nematode numbers with increasing O_3, and the same trend was noted for SO_2. There was a significant increase in chlorosis at the highest O_3 treatment. Alterations in root exudates as a result of pollutant stress may have attracted the nematodes. Most of the nematodes identified appeared to be saprophytic although Tylenchus species were not.

The original intent of this study was to expose the plants for an entire season after they had become established. Due to an unusually severe winter in 1983-84 with numerous late winter freezing and thawing events, the crop was severely damaged by frost-heaving. It was hoped that establishment of the crop over the 1984 season would provide an adequate stand for a 1985 study on the same plots. However, the crop again was damaged by the winter of 1984-85. The intensity and duration of freezing and thawing was greater than in the past few years; alfalfa is especially sensitive to frost-heaving because it lacks a strong fibrous root system (23). The situation was exacerbated at the CSRCLAP site because the shallow soil prevented deep tap root development. To have a better chance of providing useful data for NCLAN, rather than attempt another study with alfalfa, the CSRCLAP recommended that research on O_3 and SO_2 effects on four hybrids of field corn be done in 1985. This recommendation was accepted by the NCLAN Research Management Committee.

4.3. VERTICAL GRADIENTS OF O_3 CONCENTRATION IN AND ABOVE A SOYBEAN CANOPY WITHIN AND OUTSIDE OF OPEN-TOP CHAMBERS. (SERCLAP)

--A.S. Heagle, J.E. Miller, and Susan L. Corda

4.3.1. Introduction

In open-top chamber experiments, O_3 is sampled at one position (chamber center) at the height of the canopy. There is a question of whether a significant vertical profile exists throughout a plant canopy within open-top chambers and if so, how this profile compares to the vertical profile in plant canopies in the open.

The major objectives of this experiment were to determine: 1) if the position of monitoring probes used to measure O_3 concentrations in open-top field chamber experiments is adequate to characterize the O_3 dose to which plants in chambers are exposed; and 2) to compare vertical O_3 profiles above and in a soybean canopy in a chamber and in the open.

4.3.2. Materials and Methods

The study was performed at Raleigh in 1984 in a field of full-grown 'Davis' soybeans which were about 1.2 m tall in rows spaced 1 m apart. Fourteen Teflon sample tubes were used to sequentially monitor ambient air (3 minutes per tube); all tubes were at a height of 1.8 m. Individual monitoring tube efficiencies were used to calculate O_3 correction factors which were entered into the computer calculation of means. The data were summarized as 7-hr/day (0900-1600 hr EST) O_3 means using a Hewlett Packard computer. Once calibrated, the sample tubes were placed at different positions and heights in a nonfiltered-air open-top chamber containing full-grown soybeans (1.2 m tall) or at different heights over and within the soybean canopy in the open. The sample-tube efficiencies were checked during and after the study to verify whether the correction factors were accurate (Table 4.3.1). The two sample probe positions in the chamber were: 1) at chamber center, midway between two rows of soybeans, or 2) 0.5 m to the west of the first position (directly over the center and within the canopy of the west row of plants midway between the south and north end of the row). The position in the open was midway between two rows of soybeans approximately 25 meters south of the chamber.

The sample tubes in the chamber were placed at heights of 0.3, 0.6, 0.9, 1.2, 1.5, and 2.3 meters. There were two sample tubes at 1.2 m to identify potential sampling errors. Chamber monitoring lines at each height were alternated between the two chamber positions (Tables 4.3.2 and 4.3.3). At each position there were 11 to 12 days with 7-hr periods when O_3 was added to the O_3 in nonfiltered ambient air (Table 4.3.2.) and 6 to 8 days with 7-hr periods when no O_3 was added (Table 4.3.3.). The sample probe heights in the open were the same as those in the chamber but a 3.0-m sample tube was also included.

Ozone was monitored in all 14 positions on a time-shared basis with 3 minutes per position. The mean of instantaneous values monitored at 10-second intervals during the last minute of each 3-minute period was automatically corrected for sampling efficiency and recorded on magnetic

Table 4.3.1. Ozone concentrations (7-hr/day means) monitored in ambient air with long teflon tubes with individual correction factors (results are in ppb).[a].

	Correction Factor[a]	Aug. 29	Sep. 19	Sep. 20	Sep. 22	Sep. 23	Oct. 18	Oct. 19	Oct. 20	Oct. 21	Oct. 27	Mean (u)	Ratio-Individual Mean to Overall Mean	Secondary Correction Factor [b]
2	1.21	48	69	76	68	38	37	36	41	33	29	47.5	0.9916	1.008
3	1.21	47	70	76	69	39	36	37	41	34	31	48.0	1.0021	0.998
4	1.21	48	70	77	70	41	38	37	42	35	31	48.8	1.0188	0.982
5	1.20	46	70	77	69	42	37	38	42	34	32	48.7	1.0167	0.984
6	1.21	47	70	79	70	43	36	38	43	35	33	49.4	1.0313	0.970
7	1.21	47	67	77	69	41	36	38	42	34	32	48.3	1.0083	0.992
8	1.18	46	68	76	69	41	37	38	41	34	32	48.2	1.0063	0.994
9	1.21	46	68	75	65	40	37	38	41	33	33	47.6	0.9937	1.006
10	1.20	44	66	75	63	39	35	38	41	33	32	46.6	0.9729	1.028
11	1.21	45	66	76	64	40	34	37	40	32	31	46.5	0.9708	1.030
12	1.22	46	67	78	65	41	36	39	41	32	32	47.7	0.9958	1.004
13	1.28	46	70	80	64	41	37	38	40	32	32	48.0	1.0021	0.998
14	1.28	46	70	81	64	40	36	37	41	32	33	48.0	1.0021	0.998
15	1.20	46	70	79	66	40	34	38	41	32	32	47.8	0.9979	1.002
											overall u =	47.9	1.0007	0.9996

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[a] Correction factors were obtained by monitoring ambient air at one position over a two-week period and adjusting correction factors until the same ambient air concentrations (7-hr means ± 5% of overall mean) were obtained for all tubes as reported by the computer data acquisition system.

[b] The secondary correction factor is the inverse of the ratio of the individual mean to the overall mean (1/ratio).

Table 4.3.2. Effects of sample probe positions and height on O_3 concentration in a nonfiltered-air open-top chamber containing full-grown soybeans - O_3 added.

Probe Position	Date	7-hr Mean Wind Velocity in AA a/	7-hr Mean Ambient O_3 Conc. at 3.0 m	7-hr/Day Mean O_3 Conc. (ppb) per Height b/						
		m/s		2.3 m	1.5 m	1.2 m c/	1.2 m c/	0.9 m	0.6 m	0.3 m
	Sept.									
Center of Chamber	5	4.0	46	87	99	100	110	98	112	105
	7	3.3	59	106	120	126	122	125	128	125
	8	3.5	47	93	109	115	112	117	120	116
	9	3.5	37	84	104	108	106	108	111	110
	10	3.4	24	52	61	56	54	56	53	53
	11	3.6	16	59	70	73	69	75	67	69
	12	5.3	28	64	68	72	73	76	74	81
	14	4.3	48	90	93	93	94	98	99	94
	15	2.6	59	101	112	110	105	116	114	117
	16	4.4	34	75	77	79	82	83	84	87
	17	5.6	44	91	105	106	106	107	103	112
	18	3.6	37	64	65	63	56	60	67	66
	means	3.9	40	81	90	92	93	93	94	95
			% of 1.2 m	87	97	99	101	101	102	103
	Oct.									
Center of canopy-west row	24	2.4	44	92	120	120	119	123	128	125
	26	3.4	61	107	119	118	123	121	133	140
	27	4.7	24	57	55	54	57	63	71	80
	30	3.0	33	68	76	80	80	84	86	89
	1	4.4	20	66	68	71	76	86	90	91
	2	4.2	38	75	82	83	80	89	97	108
	3	4.7	51	102	132	135	133	137	132	124
	4	1.7	76	124	146	150	152	155	167	169
	5	1.2	70	102	117	122	115	127	129	121
	6	3.8	52	70	71	73	74	77	82	83
	7	2.7	29	65	69	72	68	73	71	72
	means	3.3	45	84	96	98	98	103	108	109
			% of 1.2 m	86	98	100	100	105	110	111

a/ Measured at a height of 5 meters (0900 to 1600 hr EST).
b/ Each daily value is the mean of an average of 8 scans (1 scan per 45 minutes).
c/ Both probes at same position and height.

Table 4.3.3. Effects of sample probe position and height on O_3 concentration in a nonfiltered-air open-top chamber containing full-grown soybeans - no O_3 added.

Probe Position	Date	7-hr Mean Wind Velocity a/	7-hr Mean Ambient AA O_3 Conc. at 3.0 m	7-hr/day Mean O_3 Conc. (ppb) Per Height b/						
	Aug.	m/s		2.3 m	1.5 m	1.2 m c/	1.2 m c/	0.9 m	0.6 m	0.3 m
Center of Chamber	30	4.4	51	48	48	47	47	47	49	49
	31	4.4	61	56	55	54	55	53	54	55
	Sept.									
	1	2.1	79	76	74	73	73	72	74	74
	2	3.7	77	76	74	74	73	72	74	74
	3	3.8	64	62	60	60	59	58	60	60
	4	3.5	31	30	28	28	27	27	27	27
	means	3.7	61	58	57	56	56	55	56	57
			% of AA	95	93	91	91	90	91	93
Center of Canopy-west row	Oct.									
	8	1.5	36	37	35	36	36	36	37	34
	10	4.0	48	49	48	50	48	48	49	47
	11	5.4	53	53	53	53	53	53	52	52
	13	4.7	48	46	46	47	47	47	47	46
	14	3.4	49	46	47	47	47	46	47	46
	15	1.4	45	44	43	44	43	44	45	44
	16	1.3	55	53	52	52	54	51	53	52
	17	1.3	20	21	21	20	21	20	20	20
	means	2.9	44	44	43	44	44	43	44	43
			% of AA	100	98	100	100	98	100	98

a/ Measured at a height of 5 meters (0900 to 1600 hr EST).

b/ Each daily value is the mean of 8 or 9 scans (1 scan per 45 minutes - 0900 to 1600 hr EST).

c/ Both probes at same position and height.

tape. The daily 7-hr mean (0900-1600 EST) O_3 concentrations were used for all comparisons. Results are reported in parts per billion (ppb) O_3.

Wind velocity was measured at 5 m above the ground at our site and was summarized as daily 7-hr means.

4.3.3. Results

Checks on the monitoring efficiency of individual tubes midway through and immediately after the monitoring period showed that the efficiencies remained fairly constant over the period (Table 4.3.1). This allowed for the development of a secondary correction factor (Table 4.3.1) which can be used to make minor adjustments in the data if needed.

The range in 7-hr mean ambient O_3 concentrations during 10 days of monitoring using calibrated sampling tubes was from 46.5 to 49.4 ppb. The overall mean was 47.9 ppb (Table 4.3.1).

Chamber Vertical Profile - O_3 Added. Ozone concentrations decreased with increased height at both chamber positions when O_3 was added (Table 4.3.2). It is apparent that the vertical position is more important, especially from 1.2 to 0.3 m, for the portion of the plant canopy adjacent to the chamber walls than for the portion of the canopy nearer the chamber center. For the canopy near the center, the overall concentration difference between 0.3 m and 1.2 m and between 1.5 m and 1.2 m was 3% (Table 4.3.2). For the position at the center of the west-row canopy these values were 11 and 2%, respectively.

Chamber Vertical Profile - No O_3 Added. The variation in measured O_3 concentrations with height was small. We do not know whether the differences were due to height or monitoring error (Table 4.3.3). The most significant finding was that O_3 concentrations as a percentage of ambient (at 3.0 m) were consistently less (92% of AA) at all heights at the center position than at all heights within and above the west row canopy (99% of AA). However, measures at the chamber center were taken during August and early September when leaves were physiologically more active than when measures at the west row were taken (October). Comparisons performed when leaves are in similar physiological condition might show smaller differences caused by position than were observed here.

Effect of Height Within and Over a Soybean Canopy in the Open. Differences in O_3 concentrations between 3.0 and 1.2 m indicated in Table 4.3.4. were probably due to monitoring error. However, differences between 0.9, 0.6, and 0.3 meters height appeared real with a decrease in O_3 concentration with decreasing height. For the period Aug. 30 to Oct. 16, the mean 7-hr/day O_3 concentration at 0.3 meter was about 10% less than at 1.2 meters.

4.3.4. Conclusions

In chambers with about 60 ppb added to ambient air, a vertical O_3 gradient exists which is much greater near the chamber panel than at chamber center. This gradient is opposite to that which occurs in ambient

Table 4.3.4. Ozone concentrations at different heights within and above a full-grown soybean canopy (1984).

Month & Day	Wind Velocity [a] m/sec	7-hr/day Mean O_3 Conc. (ppb) per Height/m						
		3.0	2.3	1.5	1.2	0.9	0.6	0.3
Aug.								
30	4.4	51	52	50	53	48	45	44
31	4.4	61	60	60	62	61	60	59
Sept.								
1	2.1	79	79	77	82	81	78	72
2	3.7	77	77	77	79	79	76	69
3	3.8	64	65	63	66	64	59	55
4	3.5	31	30	28	30	31	29	28
5	4.0	46	47	45	47	47	45	44
7	3.3	59	59	58	60	61	59	54
8	3.5	47	47	47	49	48	46	44
9	3.5	37	37	35	37	35	34	32
10	3.4	24	25	23	26	21	18	15
11	3.6	16	16	16	17	15	13	12
12	5.3	28	28	28	30	28	26	25
14	6.4	48	48	47	51	49	46	44
15	4.3	59	59	57	59	59	57	54
16	2.6	34	34	34	36	35	33	30
17	4.4	44	44	43	45	44	42	39
18	5.6	37	37	37	39	35	36	31
24	2.4	44	43	41	44	45	41	38
25	2.2	47	47	46	48	48	47	44
26	3.4	61	60	59	62	63	62	57
27	4.7	24	24	23	24	24	22	20
30	3.0	33	33	32	35	32	29	25
Oct.								
1	4.4	20	19	19	20	18	19	17
2	4.2	38	37	37	38	39	37	35
3	4.7	51	51	50	53	51	50	48
4	1.7	76	77	75	79	76	74	67
5	1.2	70	70	68	74	69	66	62
6	3.8	52	52	51	54	50	48	42
7	2.7	32	34	32	35	32	29	24
8	1.5	36	37	35	37	36	35	31
10	4.0	48	48	48	50	49	45	42
11	5.4	53	53	53	55	54	52	46
13	4.7	48	48	47	49	48	48	45
14	3.4	49	50	50	51	53	51	48
15	1.4	45	46	45	46	46	46	42
16	1.3	55	55	55	58	55	54	52
means	3.56	46.6	46.7	45.7	48.1	46.7	44.8	41.5
% of 3m		100	100	98	103	100	96	89
adjusted means [b]		46.9	48.0	47.1	48.3	46.6	44.7	41.6
% of 3m		100	102	100	103	99	95	89

[a] measured at a height of 5 m on site.

[b] adjusted for differences in AA concentrations during calibration after initial correction factors were obtained. The secondary correction factors shown in Table 1 were used.

air where less O_3 occurs near the ground than at greater heights. In chambers with no O_3 added, vertical gradients are negligible and thus, do not mimic the vertical gradient in a soybean canopy in the open. In terms of monitoring accuracy for open-top chamber experiments with soybeans, it appears that monitoring at canopy height in the center of a chamber slightly underestimates (5-10%) O_3 concentrations at some positions in NF chambers with or without O_3 added.

The chamber causes a vertical O_3 profile which differs from that which occurs in ambient air. The difference ranges from a reverse profile in chambers with O_3 added to a lack of a profile in nonfiltered-air chambers with no O_3 added. Overall, these differences amount at most to about a 10% difference in mean O_3 concentration from what occurs at different heights in ambient air.

4.4 QUALITY ASSURANCE FOR 1984 (NWRCLAP)--Grady E. Neely and James R. Miller

4.4.1. Air Monitoring

A systems evaluation of quality assurance (QA) procedures for instrumentation monitoring and dispensing of air pollutants was made September 13-21, 1984 at each of the NCLAN sites by W.E. Hogsett, scientist from the Corvallis Environmental Research Laboratory (CERL). He indicated in his report [filed with the NCLAN Quality Assurance Officer (QAO) at CERL] that personnel at all NCLAN locations were following approved QA procedures for air monitoring and data acquisition. In some instances there was a need to increase personnel awareness of the concern for good up-to-date initialed record keeping of calibrations, daily checklists, and logbooks.

The annual performance audit of air monitoring analyzers at each NCLAN site was conducted June 6-August 16, 1984 by personnel of the Research Triangle Institute (RTI), Research Triangle Park, North Carolina 27711. The audit results are given in the report entitled, "Fifth Performance Audit of National Crop Loss Assessment Network," by J.L. McKee, R.W. Murdock, and R.C. Shores and is on file with the QAO in Corvallis. The audit was conducted under EPA Contract No. 68-02-3767.

The accuracies of the analyzers at all research locations audited in 1980, 1981, 1982, 1983, and 1984 are shown in Table 4.4.1. A result of excellent, satisfactory, or unsatisfactory indicates the response of the analyzer was within 5%, 5-15%, or greater than 15%, respectively, of the known amount of standard gas presented to the analyzer. A summary of the results for 1984 reveal that for the 25 O_3 analyzers audited, 20 were excellent and five were satisfactory. Of the 10 SO_2 instruments audited, two were excellent and eight were satisfactory. The results of the audits for the two total oxides of nitrogen monitors show that all of the channels for one analyzer were satisfactory and for the other analyzer two were excellent and one satisfactory. No carbon dioxide analyzers were in use this year.

No deficiencies in calibration standards were noted at the various sites during the RTI instrumentation audit. The deficiencies noted last year from using standards which were past their certification date have been corrected.

Table 4.4.2 gives the results of the zero and span checks conducted at each site. Zero and span checks data give an indication of the precision of the analyzers at the 95% confidence level.

To more nearly determine treatment concentrations in NCLAN studies, a correction factor for each chamber is calculated from the measured line efficiency value. Mean percent efficiencies for teflon lines used in monitoring ozone in treatment chambers at each site (Table 4.4.3) ranged from 76 to 103. Higher efficiencies at Shafter and Corvallis sites were from having subtracted instrumentation differences from the values.

Table 4.4.1. Summary of NCLAN analyzer audits from 1980 through 1984

Audit Site and Date	Ozone[a/]			Sulfur Dioxide			Nitrogen Oxides			Carbon Dioxide			Total
	E	S	U/I	E	S	U/I	E	S	U/I	E	S	U/I	
Raleigh													
Sept. 1980					1	1							2
July 1981		4		2	2				1				9
Sept. 1981	4			3	1				1				9
Sept. 1982	3	2		2			1						8
Sept. 1983	2	1			1		2						6
Aug. 1984	4	1											5
Beltsville													
July 1980			1		1								2
July 1981		1	1		2						1		5
Sept. 1981	2	1		1	1								5
Sept. 1982	3	2			1	1							7
Sept. 1983	5	1				1							7
Ithaca													
Sept. 1980	1	2	1	1	1								6
July 1981	4			2	2						1		9
Sept. 1981	5			1	3							1	9
Sept. 1982	4	1		2	2								9
Sept. 1983		4		2	2		1						8
July 1984	4	1		1	3				1				10
Riverside													
Sept. 1980	1	4											5
July 1981	2	1	1										4
Argonne													
July 1981	2	3			3		1						11
Sept. 1981	3	1	1	2		3	1		1				12
Sept. 1982	1	2		2	1				1				6
Sept. 1983	2	1	2	1	3				1				9
July 1984	3	2			4		1						10
Shafter													
Sept. 1981	3		1										4
Aug. 1982	2	2											4
Sept. 1983	2	2											4
July 1984	3	1		1									4
Livermore													
Sept. 1981	5			4							1		10
Sept. 1982	4			2	2						1		9

Table 4.4.1. Continued.

Audit Site and Date	Ozone			Sulfur Dioxide			Nitrogen Oxides			Carbon Dioxide			Total
	E	S	U/I	E	S	U/I	E	S	U/I	E	S	U/I	
Corvallis													
July 1980	2				1			1					4
July 1981	2			1				1					4
Sept. 1981	2			1									4
Sept. 1982	1	1			1		1						4
Sept. 1983	2			1			1	1					4
June 1984	6				1								7
Totals													
1980	4	6	4	1	4	1		1					21
1981	10	9	2	7	9			2	1	2			42
1981	22	4	2	11	6	3	1	1	2	1		1	54
1982	18	10		7	7	1	2		1	1			47
1983	13	9	2	3	6	1	4	1	1				38
1984	20	5		2	8		1	1					37

a/ E = Excellent; S = Satisfactory; U = Unsatisfactory; I = Inoperative.

Table 4.4.2. Summary of NCLAN analyzer precision in 1984

Site	Analyer	Serial Number	Date	Pts	% Mean	Std. Dev.	95% Probability	
							Upper	Lower
Argonne	Bendix/O_3	32937	07/29-09/28	21	-1.5	2.7	3.7	-6.9
	Bendix/O_3	32977	07/30-09/28	25	-3.5	5.6	7.5	-14.6
	Bendix/O_3	30045-2	07/13-08/25	13	-0.6	2.6	4.5	-5.8
	Bendix/O_3	26761-11	08/26-09/28	15	-0.4	1.9	3.2	-4.1
	Bendix/O_3	26761-15	07/29-09/28	19	-0.3	1.3	2.2	-2.8
	Bendxi/O_3	7503	05/07-10/29	42	-0.6	3.3	6.0	-7.1
Boyce Thompson	MLABS/O_3	331	06/60-10/08	27	-2.6	2.7	2.8	-7.9
	MLABS/O_3	167	07/07-10/08	17	-2.7	3.9	4.9	-10.3
	MLABS/O_3	283	06/06-07/07	9	0.6	6.9	14.1	-13.0
	MLABS/O_3	300	06/06-10/08	24	1.5	2.7	6.8	-3.8
	MLABS/O_3	169	07/12-10/08	20	-0.8	4.8	8.6	-10.3
	Bendix/O_3	26761-30	06/20-07/06	4	-0.9	3.1	5.1	-7.0
	Bendix/O_3	26761-74	04/27-06/19	19	0.1	4.9	9.7	9.6
	TECO/SO_2	8433-100-S	06/05-10/08	25	-4.3	5.8	7.1	-15.8
	TECO/SO_2	9896-113-S	06/05-10/08	25	-3.5	4.7	5.7	-12.7
	TECO/SO_2	5697-76	06/05-10/08	26	-4.3	6.2	7.9	-16.4
Shafter	Dasibi/O_3	1183	03/18-10/09	42	-2.1	0.6	-1.0	-3.2
	Dasibi/O_3	1120	03/18-10/09	42	-1.5	1.0	0.6	-3.4
	Dasibi/O_3	1980	03/18-1009	42	0.4	0.6	1.4	-0.8
Raleigh	Bendix/O_3	032759	06/29-10/19	17	0.6	5.4	11.3	-10.0
	Bendix/O_3	083895	06/29-07/11	4	2.8	6.4	15.4	-9.8
	Bendix/O_3	145521	07/12-10/19	13	1.0	5.4	11.7	-9.7
	Bendix/O_3	196060	03/27-08/10	18	-4.0	5.7	7.2	-15.3
	Bendix/O_3	196060	08/15-09/28	11	1.7	5.6	12.6	-9.2
	Bendix/O_3	006753	03/27-07/12	28	-2.0	7.1	11.9	-16.0
	Bendix/O_3	071584						
	Bendix/O_3	145521	04/03-10/19	25	-0.3	5.8	11.2	-11.7
	Bendix/O_3	071579						
	Bendix/O_3	34137						
	Bendix/O_3	032748	05/01-06/20	7	0.5	6.8	13.9	-12.9
	MLABS/O_3	178	07/23-10/19	8	-2.8	13.0	22.6	-28.2
	MLABS/O_3	188	03/27-04/13	4	-0.2	3.7	7.1	-7.6

Table 4.4.3. Mean percent efficiencies for O_3 monitoring system lines by site and study in 1984[a]/

Line	Argonne	BTI	Corvallis[b]/	Raleigh		Shafter[b]/
#	Alfalfa[c]/	Forage Mixture[d]/	Alfalfa[e]/	Soybean[f]/	Forage Mixture[g]/	Alfalfa[h]/
1	83	95	97	90	91	102
2	86	93	96	91	89	99
3	85	88	97	98	82	100
4	86	96	93	91	--	102
5	84	88	95	95	82	100
6	88	87	92	96	--	100
7	88	95	97	91	--	102
8	89	87	92	96	88	101
9	89	95	97	94	85	99
10	90	95	95	86	86	101
11	89	94	95	80	90	103
12	87	92	94	--	90	99
13	87	92		93	--	101
14	87	93		85	81	101
15	88	94		--	86	98
16	88	90		--	--	--
17	88	88		94	93	--
18	88	89		--	82	--
19	85	93		81	77	100
20	87	88		76	76	101
21	86	86		78	83	--
22	87	91		88	88	100
23	84	92		91	81	96
24	86	94		89	--	101
25	86	91		81	82	99
26	84	89		82	88	99
27	84	87		87	83	99
28	85	91		82	92	100
29	85	89				102
30	84	88				
31	84	87				
32	84	86				
33	85	90				
34	86	89				

Table 4.4.3. Continued

Line	Argonne	BTI	Corvallis[b]	Raleigh		Shafter[b]
#	Alfalfa[c]	Forage Mixture[d]	Alfalfa[e]	Soybean[f]	Forage Mixture[g]	Alfalfa[h]
35	85	91				
36	86	91				
37	86					
38	86					
39	85					
40	86					
41	86					
42	86					

---

[a] (--)Indicates no line in use.

[b] Instrumentation differences subtracted out.

[c] Average of four to six sample line checks.

[d] Average of three sample line checks.

[e] Average of three to six sample line checks.

[f] Average of 10 to 32 sample line checks.

[g] Average of 3 to 60 sample line checks.

[h] Average of 30 sample line checks.

Table 4.4.4. Summary of QA checks for weight measurements.

Location	Total # Days Checked	Weights Checked	Mean % Accuracy	Range % Accuracy	% ≥ 99% Accurate
Argonne	2	16	100.00	100.00 - 99.98	100.0
Corvallis	84	177	100.00	100.20 - 99.90	100.0
Boyce Thompson	12	239	99.96	101.43 - 99.82	99.6
Raleigh	33	488	99.97	101.00 - 97.00	99.6
Shafter	17	97	100.00	100.00	100.0

4.4.2. Biological

This report summarizes the fourth year of results for NCLAN's Biological Quality Assurance Plan (BQAP). A systems evaluation of planned QA procedures was made at each location September 13-21 by W.E. Hogsett, scientist at CERL. Each station was following approved QA procedures for soil moisture and in weighing experimental plant material. Daily checklists for site operation and logbooks were found to be up to date at each location. The detailed report is filed with the NCLAN QAO at CERL. A summary of checks for weight measurement accuracy, presented in Table 4.4.4, indicates all station weights are within 1% of their true weights at least 99% of the time. Three of the five stations were always within 1% of the true weight.

All sites are in compliance with NCLAN QA documentation requirements. The NCLAN QAO will work with the BQAP for each station in 1985 making necessary additions and updating the BQAP.

SECTION 5
DATA SYNTHESIS AND ANALYSIS PROGRAM (SERCLAP)--Virginia M. Lesser

5.1. INTRODUCTION

The NCLAN program has accumulated a large amount of information on the effects of O_3 and other factors on the growth and yield of agronomic crops. The data comprise an integrated data set from a number of cooperating programs. The information in this data base is critical to the EPA mission to set secondary ambient air quality standards. Maximum use of the results from the NCLAN program and the development of a comprehensive O_3 impact model require a coordinated analysis of all data. This can be most effectively done if all data are available from a single source with one group charged with the responsibility of coordination. It is only in this framework that overall O_3 dose-yield response models can be developed and validated with respect to the precision of predicted regional and national yield losses.

The accumulated NCLAN data will be made available for continued development and verification of statistical models for regional and national crop loss assessments. The availability of the NCLAN data will allow losses to be examined and the utility of alternative O_3 dose metrics (statistics) to be investigated. The data can also be used to test other statistical approaches that might improve the handling of unbalanced data sets and more properly account for correlated errors in the data. The immediate charge of the program is for data storage and statistical analyses.

A second proposed approach to estimating O_3 effects on crop productivity is through the use of simulation models. This modeling effort, although not a current part of NCLAN, should be conducted at three levels, each of which represents a distinct level of organization. Process-oriented models should examine specific plant growth processes (e.g., leaf area development, seed production, relative growth rates, growth efficiencies) as affected by O_3 concentrations. Crop-process models should summarize plant growth by application of growth process models. Finally, in order to predict regional yield reductions, the crop-loss models, with appropriate changes, could be used in regional models for assessment purposes. This second approach was recommended but funding did not permit approval of this approach.

5.2. DATA STORAGE AND STATISTICAL ANALYSIS

5.2.1. Objective

The objective of this project is to provide a coordinated analysis of all NCLAN data on the effects of O_3 on crop production for: 1) developing a unified system of dose-response equations for the species, cultivars, and environmental conditions investigated by NCLAN, including evaluation of the adequacy of the models and model assumptions used; 2) investigation of methods of establishing degrees of confidence in regional and national dose-response predictions; and 3) providing insight into the use of alternative dose metrics and more efficient experimental designs for future studies.

5.2.2. Approach

This coordinated analysis of the accumulated NCLAN experimental data will consist of several fairly distinct steps and/or problems to be investigated. Initial steps have begun in some of these problems which are discussed briefly. This is intended to be an ongoing project with continual updating of results as additional NCLAN data are obtained. Furthermore, it is not intended that all topics will be addressed in the first year. Immediate attention will be focused on obtaining a complete file of the NCLAN data. It is anticipated that this will be on-going during the first year to assure compilation of all existing data. The format of the data included in the library is also discussed.

Storage of NCLAN data - The proposed analyses require access to all NCLAN research data. Therefore, work is currently concentrated on collecting data from all NCLAN research projects to be stored at Raleigh, with the cooperation of the individual research projects. The data for each study include detailed descriptions of the experimental design and methods, the cultural practices used, the details of exposure, air quality data, and plant response data. The data are handled and stored in such a way as to be available to other NCLAN researchers but secure from indiscriminant access. The exact data to be stored and the operational rules for handling have been developed in cooperation with the NCLAN projects. A data request form (Table 5.1) will be completed by any interested party requesting data from the library.

Data from the Raleigh and Riverside sites have been collected and formatted in the NCLAN library. Work is progressing on both the Argonne and Boyce Thompson Institute sites. The information collected for each study is grouped into three categories: 1) descriptive information; 2) air quality data; and 3) plant response data. The contents of data in each of these categories are shown in Table 5.2. The descriptive information for each study, which is given in category I, is stored in the format shown in Table 5.3. The air quality data set for the dispensing period (Data Set II(A)) consist of hourly O_3 values for each monitored plot in the study, while the air quality data for the 24-hr period (Data Set II(B)) consist of hourly O_3 values for the treatments NF, CF, and AA. Data Set II(C) may or may not exist for a given experiment depending on the experimental design. For the plant response data, Data Sets III(A) and III(B) consist of sampling unit data. Covariate/companion plot data are given in Data Set III(C) only for those experiments where the covariate was significant in prior site analysis. Soil moisture data, or more specifically data collected which dictated irrigation in ozone/moisture stress studies, are stored in Data Set III(D).

Verification of statistical models and development of regional and national response models - The NCLAN project has used several statistical models at different times depending on the nature of the response to O_3 in the particular data set being analyzed. Because of the flexibility of the Weibull (two parameter) model and its apparent effectiveness in

Table 5.1 NCLAN data request form

NATIONAL CROP LOSS ASSESSMENT NETWORK

Request for Data

A. Requestee information:
Name: ____________________ Date: ____________
Address: ____________________ Phone: ____________
____
____
____

B. Experiment(s) requested:

Year(s): ____________________

Crop(s): ____________________

Location(s): ____________________

C. Data set(s) requested:

I. Descriptive Information.

To be sent with all data requests.

II. Air Monitoring.

A. Dispensed ozone data ____________________

B. 24-hr ozone data ____________________

C. Additional pollutant dispensing data (if applicable): _____
____

III. Plant Response.

A. Yield and quality data ____________________

B. % injury data ____________________

C. Covariate/companion plot data ____________________

D. Soil moisture data ____________________

Table 5.1 Continued.

D. Method of transfer:

A) Tape (format is std or non label, 1600 or 6250 bpi, 9 track).

(Please supply tape) ____________________

B) Diskette (please supply diskette formatted with MS-DOS or PC-DOS).

i) 360 KB ____________________

ii) 1.2 MB ____________________

C) Printout ____________________

E. Intended use and projected disposition of the data:

Please include a brief description of any intended reanalysis.

If a journal article results from the data, we ask that the principal investigator(s) of the experiment review the article before submission to a journal and that the following acknowledgement be made in the article: "The authors acknowledge contribution of data from those NCLAN field sites used in this paper and review of this manuscript by the principal investigator(s), (please list names). Research funding for the NCLAN Project was provided by the U. S. Environmental Protection Agency; the project was administered by the EPA's Environmental Research Laboratory in Corvallis, Oregon." In addition, please forward a copy of the journal article to the NCLAN data library and the EPA Information Manager at ERL-Corvallis.

Table 5.1 Continued.

F. Mailing address:

NCLAN Data Library (for Distribution to RMC)
1509 Varsity Drive
Raleigh, NC 27606

FOR LIBRARY USE

Date Received: ______________________________

Date RMC notified: ______________________________

RMC action: ______________________________

approve: ______________________________

disapproved (see explanation): ____________________

Date data released: ______________________________

Explanation (if disapproved): ____________________

Table 5.2. Data sets stored in the NCLAN - Data Storage and Retrieval Library

---

I. Description Information

II. Air Quality Data

- A) Dispensing O_3 data per hour for all plots
- B) 24-hr O_3 data for AA, NF, CF, per hour
- C) Air quality data for additional pollutant

III. Plant Response Data

- A) Yield and Quality Data
- B) Plant Injury Data
- C) Companion/Covariate Data
- D) Soil Moisture Data for Moisture Stress Experiments

Table 5.3. Descriptive data set (I) stored for each experiment in the NCLAN-Data Storage and Retrieval Library.

DESCRIPTIVE INFORMATION OF EXPERIMENT

General Information

1. Site:
2. Year:
3. Crop: Common name
   Latin binomial
   Cultivar(s)

Cultural Information

1. Planting date:
2. Soil type and name:
3. Row spacing:
   Plant spacing in row (plants per meter):
4. Emergence date:
5. Starting date of exposure:
   Growth stage on this date:
6. Ending date of exposure:
   Growth stage on this date:

Exposure and Monitoring Information

1. Type of pollutants and method of pollutant addition (constant addition proportional):
2. Exposure starting and ending times per day:
3. Number of exposure days from starting to ending data:
4. Number of exposure days missed:
   (NOTE: Periods of suspended ozone dispensing due to rain or malfunction are coded as DIS=0 in ozone data sets.)
5. Sequential monitoring description:
   i) Sample duration per point (sampling interval):
   ii) Duration of one complete scan of monitoring site:

Table 5.3. Continued.

Fertilizer Application

Date	Formulation (%N:P:K)	Amount/hectare

Herbicide and Pesticide Applications

Date	Chemical Name (common/trade)	Formulation/ concentration	Amount/ha

Table 5.3. Continued.

Irrigation Method and Application

1. Criteria which dictated irrigation:

2. Description of application method (drip tube, overhead spray nozzle, hand held nozzle):

3. Irrigation dates and areas:

Plot	Dates of irrigation	Total/season (cm)

Table 5.3. Continued.

Experimental Design

1. Complete design description:
    - i) Design type:
        If split plot, whole plot factor:
        sub-plot factor:
    - ii) experimental unit:
        sampling unit:
    - iii) total # of plots:
        total # of treatment:
    - iv) # levels of ozone:
    - v) # levels other factors:

2. Treatment listing (to relate to treatment codes given in data sets which will be presented in Parts II and III of this experiment's file):

Treatment code	Description of pollutant level

Variables found in Data Set IIB (24HR)

Data Set II(B). Describe the number of samples used to determine the means listed over the 24-hr period:

Table 5.3. Continued.

Yield Response Information

Data Set III(A). Yield response.

i) Harvest date:
ii) Description of each response variable recorded:

a. Yield variables:

b. Quality variables:

c. Seasonal dispensing means:

Table 5.3. Continued.

Injury Data Information

Data Set III(B). % Injury Data. Description to include date, criteria used for estimation of plant injury, and plant areas used (leaf position on whole plant):

Data Set III(C). Companion Plots.
i) Harvest date:
ii) Description:

Parameter Estimates (With Standard Errors)

Polynomial Model(s):

Weibull Model(s):

Table 5.3. Continued.

Miscellaneous Information

1. Insect/disease problems:

2. Miscellaneous:

characterizing the crop yield losses, NCLAN has used the Weibull function as the primary dose-response model. This has permitted the use of a common model for characterizing the O_3 effects over a wide range of species and environmental conditions. With the accumulation of the many data sets now available in NCLAN, it is time to critically re-examine the use of the Weibull model, and alternative models, with the objective of finding the best method of characterizing the O_3 response. This project will critically examine the model assumptions, in particular, homogeneity of error variances over treatments and the behavior of the residuals, and investigate other models, modifications of the Weibull model or methods of analysis to take into account any inadequacies.

The development of regional and national dose-response prediction equations will be approached in two steps. The first step will concentrate on compressing the dose-response information into a minimum number of prediction equations. All homogeneous sets of responses will be represented by a common dose-response equation with the parameters of the model changing for different situations. The second step of the regional model development will involve generalizing the form of the model to encompass quantitatively different environmental conditions. Some information on water stress is currently available from field studies at several NCLAN sites. More detailed studies of the effects of water stress on the O_3 effects on plant growth are being done at Corvallis. As research information on environmental effects becomes available, the impact of significant factors will be incorporated into the response models. This will increase the scope of each prediction equation and reduce the number of distinct equations needed. The project will use the new information from each year's research to update the system of prediction equations.

Precision of predicted yield losses - We have developed (but have not shown) and have been using the measures of precision of the predicted relative yield losses for each experiment. These measures of precision do not apply to predictions made for another year or another site (even when the prediction equation is considered to be appropriate). Using the experimental results to make regional and/or national loss predictions introduces an additional source of uncertainty, that from the random variation in environments. Initial approaches to this have started with the Raleigh data.

Since the Raleigh site was the first site to be completed in the library, preliminary data analysis has dealt with the data from this site, specifically the 1981-1984 soybean studies. A method to use the variability over experiments to develop an appropriate measure of the precision of predicted yield losses for geographical regions and over time (years) is being pursued (i.e., regionalization problem). This methodology will be extended to include soybean data from the other sites when that data is available.

There will always remain, however, a major component of random environmental variation which will contribute to the degree of uncertainty in any prediction. Inadequate information is available to properly assess the magnitude of this source of uncertainty but it is important that we be as definitive as possible in stating the degree of confidence we have in our predictions. This component of the data synthesis project will examine the question of degree of confidence in regional predictions. It is anticipated that some bounds might be placed on the degree of confidence by examining the repeatability of results from similar NCLAN experiments done in different sites and/or years.

Alternative dose metrics (statistics) - To date, the seasonal mean of the 7-hr/day mean O_3 concentration has been used as the O_3 exposure metric. Some interest is being expressed in the use of a seasonal 12-hr mean. In addition to the daily time span of the mean, there are several kinds of means that might be used and which might better characterize the dose-response curves under different exposure regimes and different environmental conditions. For example, power weighted means,

$$w_p = (X^{p+1}/X^p),$$

can be used to reflect differential weighting of peaks. The simple average is given by p=0; larger values of p give increasing weight to the peak exposures. The project proposes to investigate the relative merits of different dose metrics for characterizing the dose-response. For this purpose, treatment regimes are needed which generate different distributions of O_3 exposure. Only limited data are currently available comparing effects of constant addition to proportional addition, or 7-hr to 12-hr exposures. In addition, differential weighting of O_3 concentration with respect to stage of plant development and time of day will be investigated as relevant data sets become available.

Analysis of unbalanced data and correlated errors - The experimental designs used by NCLAN frequently involve split-plot designs. Such designs have a correlated error structure; the errors associated with subplots within a whole plot will tend to be (positively) correlated. Similarly, several experiments considered simultaneously, as is done in combined analyses, will have a correlated error structure. When the data are balanced, the correlated error structure is taken into account in the conventional analyses of variance. However, the correlated error structure causes problems in the analysis of unbalanced data and the estimation of the parameters for nonlinear models. Further development of methods of data analysis and testing of hypotheses is needed for unbalanced data when nonlinear response models, like the Weibull, are being used. This project will investigate other methods of analysis that more properly take into account the correlation structure. In particular, Giesbrecht's MIXMOD (24) analysis will be investigated for possible use in the estimation of the model parameters. This will require the extension of the MIXMOD procedure to handle nonlinear models.

Optimal experimental designs - The optimum number of O_3 levels in an experimental design and the spacing of these levels varies with the specific objective of the study (or the use to be made of the dose-response curve). To date, the experimental designs used by NCLAN have emphasized the objective of characterizing the dose-response within defined levels of O_3 concentration. Such designs would not necessarily be optimum for the estimation of the relative yield loss between O_3 concentrations of 0.025 and 0.06 ppm nor for estimation of the Weibull parameters *per se*. Work is currently progressing on optimum experimental designs to meet different objectives when the Weibull dose response model is used. This aspect of the data synthesis project proposes to determine the optimum designs (for given amounts of research effort) for the different objectives and investigate strategies for experimental designs when there are conflicting objectives.

5.3. BIOLOGICAL MODELING RESEARCH

5.3.1. Introduction

This section is included, even though research will not be done, because it highlights our recommended approach to an intensive modeling effort. Such an effort was part of the original intent of the NCLAN program.

Modeling rationale - A major goal of the NCLAN program is to develop a capability for predicting the response of crops to air pollutants (i.e., O_3). The challenge that this goal represents can be placed in perspective by considering the multifactorial nature of plant response to environmental stimuli. While O_3 has a direct effect on plants, an understanding of the combined effects of O_3 with other important environmental variables (e.g., other pollutants, temperature, light, nutrients, and water) is required for a more complete assessment. Thus, the key to developing a predictive capability necessarily stems from a consideration of numerous interactions within the total atmosphere-plant-soil system.

The complexities involved in prediction become even more evident when extrapolation from one level of resolution to another is attempted (say, single plant to crop) and this, in turn, combined with projections over time (i.e., years in the future). Since it is impossible to devise experiments that cover the entire range of interactions of interest (as well as the time frame desired), the one viable alternative is to use computer-based simulation models to predict crop response to pollutants.

Biological modeling: definition of purpose - The uses of models may be classified in a variety of ways: to summarize data (SM), to predict behavior within the range of the data base (interpolative prediction, IP), to predict behavior outside the range of the data base (extrapolative prediction, EP), to manage research (RM), and to interpret behavior (IN). The Weibull model is an example of an empirical model that is useful for SM, IP, and RM. The purpose of a biological modeling approach is to develop an additional capability for EP and IN.

Summary of biological model-building philosophy

1) There is a need for a modeling approach which can be used for extrapolative prediction in NCLAN. Crop growth simulators can be used to accomplish this.

2) Crop growth simulators that are developed for regional use should be based on a readily-attainable data base and should be kept as general as possible. Hence, we envision models that might best be termed "semi-mechanistic" in nature. Such models will allow complexity to be minimized by including only key relationships.

3) Since complexity should be minimized, it is essential to identify those key interactions which affect crop response to O_3 stress, (i.e, water and nutrient stress, temperature, other pollutants).

4) These crop growth simulators should be validated against the same data from which the dose-response models are developed (i.e., for interpolative prediction). We would not have confidence in using a model for EP use if its IP performance was poor.

5.3.2. Modeling Procedure

Biological modeling should be based on the NCLAN database. This modeling should be conducted at three levels, each of which represents a distinct level of organization and, hence, utilizes different types of data sets.

Level 1: Process-oriented models - These models should use specific plant growth processes (such as leaf area development, seed production, relative growth rates, growth efficiencies, etc.) as related to O_3 concentration. These models will be valuable for understanding the effects of O_3 on specific growth processes.

Several modeling studies were initiated at Raleigh, NC to quantify the effect of O_3 on various growth processes in soybean. Several of these studies are summarized and form the basis of a procedure to be followed across NCLAN sites for site-to-site comparisons.

1) Lieth and Reynolds (25) are developing a model to predict the impact of multiple episodic exposures of O_3 on the relative growth rate of leaves.

2) Some work has been done to fit models to data sets of plants grown at various concentrations of O_3. One model is:
$L(t) = LMAX/(1+((LMAX-L(to))/L(to) * \exp(-k(t-to)))$
where L(t) is the leaf area of the plant at time t, LMAX is the maximum leaf area attained, L(to) is the initial leaf area at time to and k is the growth rate parameter. The objective is to examine the relationships of k and LMAX to O_3 concentration.

3) The Gent model (26) for the rate of increase in the size and dry weight of soybean pods (a logistic model) could be fitted to soybean data sets to examine the effect of O_3 on model parameters.

4) The capability to predict plant phenology is essential in developing a forecasting capability for crop production over large areas. Hence, plant phenology models should be developed. For example, the models of Doraiswamy and Thompson (27), which use environmental variables such as maximum and minimum daily air temperatures and soil moisture deficits to predict phenological progression, should be tested for predicting phenology in soybean. Again, the effect of O_3 on the fitted model parameters is of interest.

5) We have conducted a three-year study on leaf area development and light interception by soybean. Numerous models have been

developed to estimate growth efficiencies, leaf area development, and yield as a function of the duration of growth. These should be examined for NCLAN use.

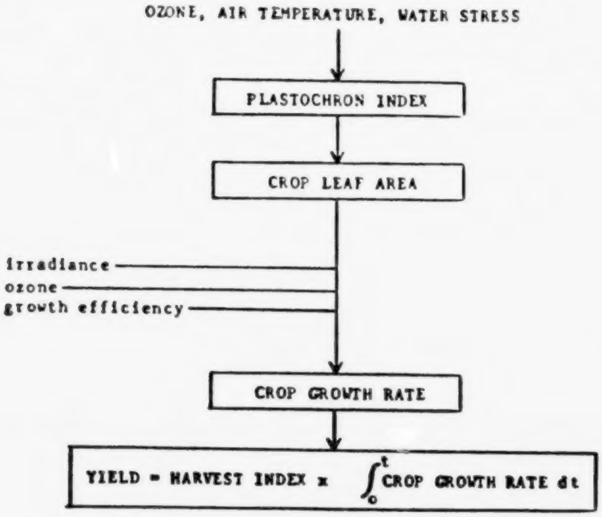
Level 2: Crop-oriented models - These models will summarize plant growth in terms of the relative contribution of different growth processes, such as those described above, to final yield. Hence, these models will integrate the findings of the plant process models (i.e., Level 1) to predict crop response to O_3.

One approach would be to develop models based on key interactions within the soil-plant-atmosphere system. For example, we are currently looking at crop growth rate as follows:

$$\text{CROP GROWTH RATE} = S \times (1 - \exp[-k \times LAI]) \times E$$

where S is the daily light integral incident on the top of the crop canopy, k is the canopy light extinction coefficient, LAI is the leaf area index, and E is the efficiency of use of the intercepted light in net dry matter production (28, 29). Models of this type, where E varies as a function of O_3 concentration, could be tested against two seasons of field data collected in Raleigh.

This crop growth model has potential for extension in a number of ways, all of which integrate various aspects of process-level interactions. For example, LAI can be found as a function of plastochron index (30) and plastochron index is highly correlated with air temperature (31,32). It is highly probable that the rate of the plastochron development (33) would be affected by O_3. Furthermore, if we assume that the harvest index within a cultivar is reasonably predictable (Sinclair, Gainesville FL; personal communication), then yield can be found from the following simplified model [modified from Sinclair & Spaeth, 1982 (34)].


OZONE, AIR TEMPERATURE, WATER STRESS
PLASTOCHRON INDEX
CROP LEAF AREA
irradiance
ozone
growth efficiency
CROP GROWTH RATE
$\text{YIELD} = \text{HARVEST INDEX} \times \int_0^t \text{CROP GROWTH RATE}\, dt$

This model, which requires a very minimal data set, integrates a critical set of key interactions that are important in determining the final yield of crops. Although this model is simple, various extensions have proven to be very powerful as a tool in analyzing crop growth (35).

We are also examining extensions of the above crop growth model in terms of the partitioning of dry matter into various components [e.g., vegetative (leaf, stems, roots) and reproductive growth] using a modified version of the model by Muchow & Charles-Edwards (36). Other simplified models, [i.e., the model developed by Heilman et al. (37)], have potential for examining the level of detail necessary to adequately predict crop growth. Alternative models for purposes of comparison and for identifying those growth processes necessary to predict pollutant effects should be developed.

Level 3: Regional-oriented models - These models will be used to predict regional crop-loss from information based on the Level 2 models; the intent will be to develop models that are based on general crop responses as described above. Regional yield models such as those developed by Hayes et al. (38), Holt et al. (39), and van Keulen and de Milliano (40) should be examined for their potential use. Each of these approaches is based on identifying key processes that affect crop growth and evaluating differential responses across regions. These models should be modified to include significant Level 2 models.

SECTION 6

AN EVALUATION OF THE KRIGING METHOD AS APPLIED TO THE NCLAN PROGRAM (NWRCLAP)--Allen S. Lefohn, H. Peter Knudsen, Jennifer Logan, Jeanne Simpson, and Chandrakant Bhumralkar

6.1. INTRODUCTION

In 1982, the NCLAN program used a statistical technique called kriging to estimate the seasonal ambient O_3 concentration from 1978 to 1982 (41) for each of the major crop growing areas of the United States. The NCLAN program used data from air quality monitoring data bases, obtained from State and Local air monitoring stations (SLAMS), archived in the U.S. EPA'S Storage and Retrieval of Aerometric Data System (SAROAD). The O_3 data were characterized by seasonal 7-hr means (0900 to 1600). The seasonal O_3 estimates were used to predict the economic benefits anticipated by lowering the O_3 levels in the United States (42).

To assess the limitations associated with the kriging methodology as applied to NCLAN's predictions, NCLAN requested that a peer-review panel evaluate NCLAN's usage of kriging to estimate mean O_3 concentrations for crop growing regions of the United States. The panel addressed the following tasks.

1) Review NCLAN's application of the kriging technique to predict 7-hr seasonal O_3 levels for crop growing areas of the United States.

2) Identify alternative kriging techniques for projecting O_3 levels in geographic areas where monitoring data are available to characterize distributions.

3) Compare alternative kriging techniques with the original kriging model and provide some indication whether an improvement could be made to the existing projection approach.

As part of the review, the panel received the following information:

1) The 1982 NCLAN Annual Report which described the application of kriging for estimating O_3 concentrations in crop growing areas (41);

2) Maps illustrating the predicted 7-hr seasonal O_3 concentrations for the United States for 1978 through 1982 (supplied by the Oak Ridge National Laboratory); and

3) An economic summary report entitled, 'The Economic Effects of Ozone on Agriculture' (42).

After reviewing this material, the preliminary peer-review findings were summarized:

1) The computer program used to perform the kriging incorrectly calculated the diagonal elements of the kriging matrix (the coefficients of the simultaneous equations).

2) The resulting kriging estimates for agricultural areas might be biased low because the majority of the monitoring data used in the analysis were located in or near urban areas. These urban monitoring sites could have experienced depressed levels of O_3 because of nitrogen oxide titration.

3) The resulting kriging estimates for agricultural areas might be biased high because urban monitors included in the analysis, located downwind of a city-center area, could systematically experience high O_3 concentrations if they consistently sampled the urban plume.

4) Concern was expressed about the adequacy of the variogram models used in 1982. No experimental variogram plots were available to confirm whether the model was a good fit.

5) An independent verification should be made comparing estimated 7-hr seasonal averages to actual 7-hr seasonal values derived from monitoring site data that were not used in the original study.

As a result of the above concerns, the peer-review panel obtained the 1) original 7-hr, 5-month seasonal monitoring data and 2) computer software used in the original 1982 NCLAN study. The panel proceeded to perform the following analyses to provide answers to the concerns raised above.

1) The kriging program used in the 1982 study was changed to correctly calculate the diagonal elements of the kriging matrix. Using the corrected program, new kriged estimates were calculated for the 1979 and 1982 growing seasons. In this report, this new model will be referred to as the 'Corrected Model'.

2) The Corrected Model for each year was compared to the original model constructed in 1982. The original model is labeled 'Original Model'. This model estimated 7-hr seasonal O_3 concentrations for the center of a cell. The comparison between the 'Corrected' and Original' models determines the magnitude of the errors introduced into the Original Model by the incorrect calculation of the diagonal elements of the kriging matrix used in the 1982 study.

3) The effects of exclusion of certain urban data were studied by adding back into the data base the monitoring sites originally excluded and constructing another model for 1979 and 1982. The model for each year is referred to as 'City-Center Inclusion Model'.

4) Using a standard geostatistical software package written by Dr. H.P. Knudsen in the mid-1970s and used extensively by the mining industry, the 1979 and 1982 data were re-analyzed to determine

appropriate variogram models to use for kriging. New kriging estimates were made using Dr. Knudsen's software. This software estimated 7-hr concentrations for entire area rather than for the center of a cell. These models are referred to as the 'Ordinary Kriging Models'. These models were then compared to the original models constructed in 1982.

5) Hourly mean O_3 data were obtained for a number of monitoring sites not included in the 1982 NCLAN study. These data were used as independent comparisons to the 7-hr seasonal estimates made by the (1) 'Original Model', (2) 'Corrected Model', and (3) 'Ordinary Kriging Model'.

6.2. KRIGING

Kriging is a statistical tool developed by George Matheron, a French mining engineer, to estimate the grade of a block of ore from samples taken in or near the block. Although this technique is widely used by the mining industry, it is not yet well known outside the field of Earth Science and the terminology is different from classical statistics.

Kriging is a linear estimator of the form

$$Z^*(x) = \sum_{i=1}^{n} \lambda_i \, Z(X_i) \qquad (1)$$

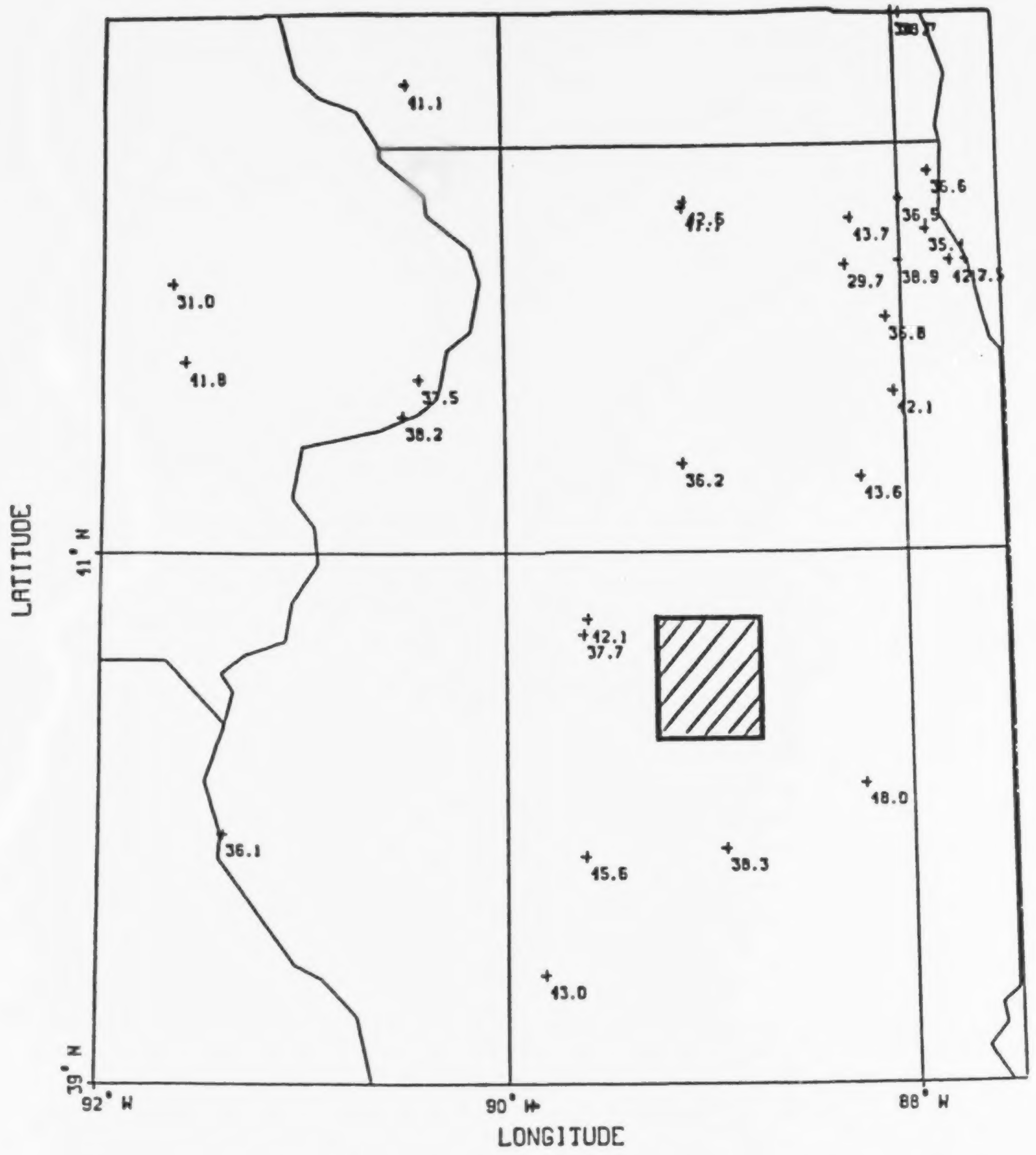
where $Z^*(x)$ = the estimate of the area x,
λ_i = weight applied to sample λ_i, and
$Z(x_i)$ = the value of the sample located at x_i.

Kriging has the same form as a classic moving average, the only difference being how the weights, λ_i, are determined. In the classic inverse distance squared interpolation the weights are proportional to the inverse squared distance of the sample $Z(x_i)$ from the point being estimated. In kriging, however, the weights, λ_i, applied to each sample value are calculated in such a manner that the resulting estimate is unbiased and optimal in the sense that the variance of the estimation error is minimized. Kriging is a best linear unbiased estimator.

The technique is best presented by an example. Figure 6.2.1. illustrates a portion of Illinois (cross-hatched area) for which an estimate of the 7-hr seasonal O_3 concentration is desired. The locations of nearby O_3 monitoring stations are also shown. For this example, the nearest seven samples were used to estimate the cross-hatched area. At the bottom of the figure, the calculations used to form the kriged estimate are shown.

The variance of the estimation error, or estimation variance as referred to in spatial statistics, is defined by

$$\sigma^2_e = E[Z^*(v) - Z(v)]^2 \qquad (2)$$


LATITUDE
41° N
39° N
92° W
90° W
88° W
LONGITUDE
41.1
31.0
41.8
37.5
38.2
36.2
36.5
43.7
29.7
38.9
35.8
42.1
43.6
42.1
37.7
48.0
36.1
45.6
38.3
43.0

```
 Site Id.     Latitude  Longitude      Ozone     Krising weight
*********     ********  *********   ********     **************
146080024      40.6886    89.6103    37.7000         0.1767
146120001      40.7461    89.5864    42.1000         0.1668
141740006      39.8744    88.9250    38.3000         0.1825
141140004      40.1239    88.2297    48.0000         0.1761
147280010      39.8439    89.6056    45.6000         0.1023
144080001      41.3325    89.1094    36.2000         0.0983
148320007      41.2778    88.2203    43.6000         0.0973
```

Kriged estimate = 41.59 ppb ozone

Figure 6.2.1. Location of monitoring stations and their 7-hr seasonal ozone concentration data (ppb) near an Illinois $\frac{1}{2}\text{x}\frac{1}{2}^{\circ}$ grid for which an estimate of the 7-hr seasonal O_3 concentration is calculated via kriging.

The estimation variance can be calculated by using another tool derived from spatial statistics called the variogram. The variogram is a tool used to quantify the spatial correlation between sample values and is defined by

$$\gamma(h) = \tfrac{1}{2}n_h \Sigma[Z(x+h) - Z(x)]^2 \qquad (3)$$

where n_h = number of pairs a distance h apart,
$\gamma(h)$ = variogram value for the distance h,
$Z(x)$ = the value of the sample at point x, and
$Z(x+h)$ = the value of the sample at point x+h, where h is distance between the position x and x+h.

The variogram is determined by squaring the differences between all sample values at a given distance (h) apart divided by twice the number of pairs used in the calculation of $\gamma(h)$. This calculation is repeated for varying distances. To graphically depict the relationship between the variogram value and the distance between monitoring sites, the $\gamma(h)$ values are plotted. Figure 6.2.2. shows an example of a typical variogram.

The value where the variogram plot levels off is termed the sill of the variogram. The sill value is the variance of samples within the field of study. The distance at which the variogram reaches the sill value indicates the limit or range of spatial correlation. Beyond this distance, samples are statistically independent. For the variogram described in Figure 6.2.2., the range of spatial correlation is approximately 120 kilometers.

The value of the variogram as the distance approaches zero is called the nugget effect. In Figure 6.2.2. the nugget is approximately 7 ppb^2. Because two samples at the same point should have the same value, the value of the variogram is theoretically zero. A positive nugget value is usually observed. This is caused by small scale structures or measurement errors.

The variogram shown in Figure 6.2.2. is called an experimental variogram. In actual kriging calculations, a model is fitted to the experimental variogram and the model substituted for the experimental variogram. One of the commonly used variogram models is called the nested spherical variogram model. This model is shown as a smooth line in Figure 6.2.2.

Once the variogram is estimated, it can be used to calculate the estimation variance for any linear estimator by the following formula:

$$\sigma_e^2 = 2 \sum_{i=1}^{n} \lambda_i \, \gamma(i,v) - \gamma(v,v) - \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_i \lambda_j \gamma(i,j) \qquad (4)$$

where $\gamma(i,v)$ = the value of the variogram for the distance separating the sample i and the area (v) being estimated,
$\gamma(v,v)$ = the average value of the variogram within the area, and
$\gamma(i,j)$ = the value of the variogram for the distance separating sample i and sample j.

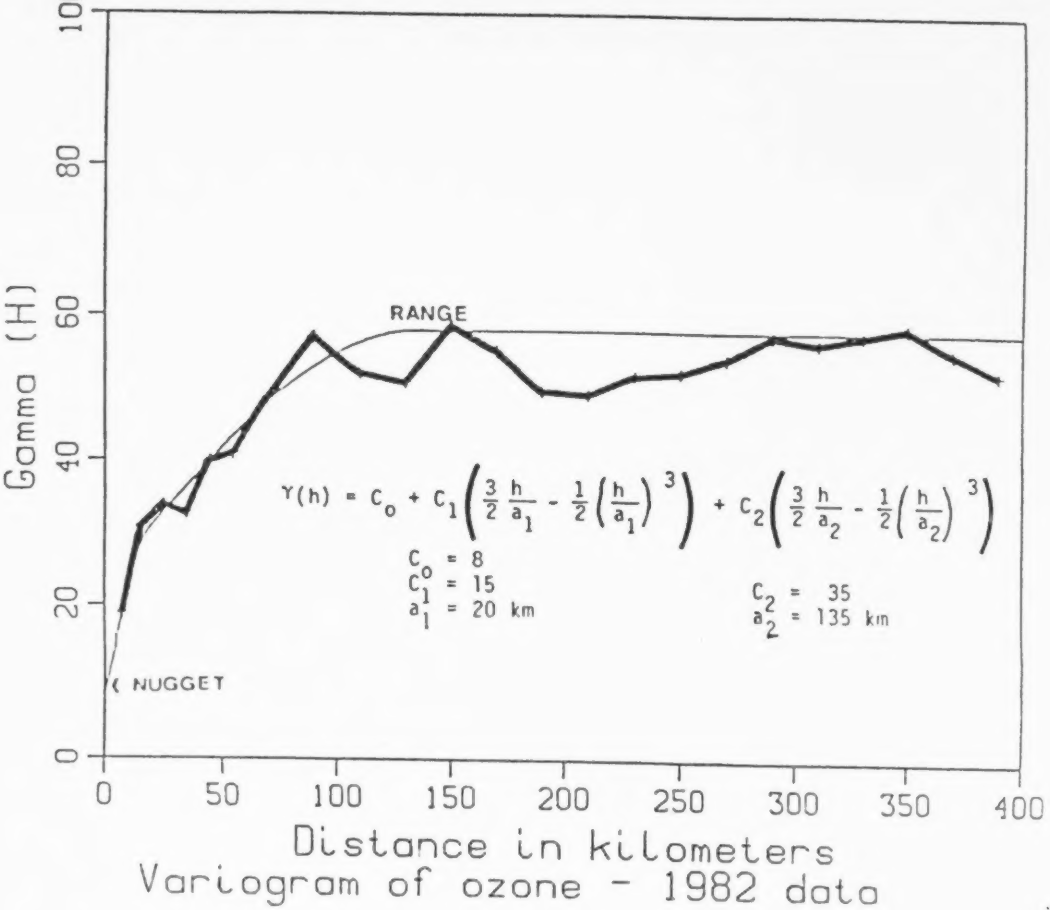


Figure 6.2.2. Example of a typical variogram.

The magnitude of the estimation variance is a function of the following factors:

1) The distance of the samples to the area being estimated. This is represented by the first term in equation 4. The estimation variance increases as the distance of the sample from the area being estimated increases.

2) The size of the area being estimated. This is represented by the second term. Using the same data, an estimate of the 7-hr mean O_3 concentration for an entire state would likely have less error than an estimate of the mean concentration for a five acre field.

3) The spacing and number of samples used in the estimation. The third term captures the intersample correlations. It is preferable to have the data regularly spaced rather than in clusters. If the data are clustered, the third term will be small and hence, the estimation variance will be larger than if the data were regularly spaced across the field.

4) The spatial correlation of the variable as captured by the variogram.

5) The weights λ_i assigned to each sample.

Equation 4 is the key to deriving an optimal spatial estimator. Given 1) a set of samples, 2) a specific area to be estimated, and 3) a specific variogram, the best or optimal estimator has minimum estimation variance. For example, in Equation 4, the only variables are the weights (λ_i) assigned to each sample. Thus, the optimal estimator (e.g., 7-hr mean concentration) can be derived by finding the set of weights that minimizes the estimation variance subject to the constraint that the estimator is also unbiased. Using calculus to find the minimum of the estimation variance, the following kriging equations are obtained.

$$\sum_{i=1}^{n} \lambda_i \bar{\gamma}(i,j) - \mu = \bar{\gamma}(J,v) \qquad (5)$$

n equations for j = 1, n and $\sum_{i=1}^{n} \lambda_i = 1$
μ = Lagrange multiplier

This set of simultaneous equations is solved to get the unknown weights (λ_i). Once the weights are calculated, the estimate can be formed and the estimation variance calculated.

6.3 NCLAN'S 1982 USE OF KRIGING

In estimating 7-hr seasonal O_3 concentrations, several decisions had to be made concerning the air quality monitoring data to be used. First, not all monitoring stations had a complete record of O_3 measurements at the monitoring site (due to equipment maintenance, malfunctions, etc.). Criteria had to be established to determine whether sufficient data were collected at a specific monitoring station to form a reliable seasonal average. For a 5-month growing season, the minimum acceptable data set must have had 4 months of data and each month must have had 16 or more days when all 7 hours of data were present (41). For stations meeting this criterion, the seasonal average was calculated by stratifying the data by each hour, calculating the average for each hour, and then averaging the 7 hourly averages. No data from a station that met the above criterion were excluded.

The second important decision focused on the selection of stations to be included in the analysis. Of particular concern were monitoring stations located in cities. In urban settings, the O_3 concentration may be less at city-center than rural locations because nitric oxide in the city would reduce O_3 at ground level. Therefore, using city-center monitoring stations to predict rural O_3 levels might provide low O_3 estimates. Because of this concern, specific monitoring stations located in large metropolitan areas were not included in the analysis. The specific monitoring sites deleted in the 1982 study are discussed in Section 6.4.2. The original selection of which city- center monitoring data to delete was a subjective decision made by the NCLAN investigator.

Figure 6.3.1. shows the monitoring sites used for the 1979 kriging estimates. Data from these monitoring sites were used to estimate the 7-hr seasonal O_3 concentration for May through September in each ½° by ½° grid cell in the United States. Each individual cell was estimated using the nearest 5 monitoring sites. If 5 monitoring sites could not be found within 500 kilometers, the cell was estimated by using a site's 7-hr average if the site was located within 30 km; the cell was not estimated if either of the two criteria were not met. Figure 6.3.2. shows the estimated 7-hr mean concentration for May through September using 1979 data. The blank areas indicate where no O_3 estimates were made due to insufficient data. Because the Northern Great Plains lacked monitoring data, much of this area was not estimated.

Figure 6.3.3. shows the monitoring sites used in estimating 1982 O_3 7-hr seasonal means. Figure 6.3.4. presents the 1982 kriged results. The 1979 and 1982 results were selected for analysis by the peer review panel and will be discussed in detail.

The variograms used in kriging the 1979 and 1982 data were derived from a linear model rather than from the spherical model. The equations for the 1979 and 1982 model were

1979 Variogram Model

$$\gamma(h) = 37.7 + 0.417\ (h) \text{ for } h \text{ less than 117 km.}$$
$$= 86.4 \text{ for } h \text{ greater than 117 km.}$$

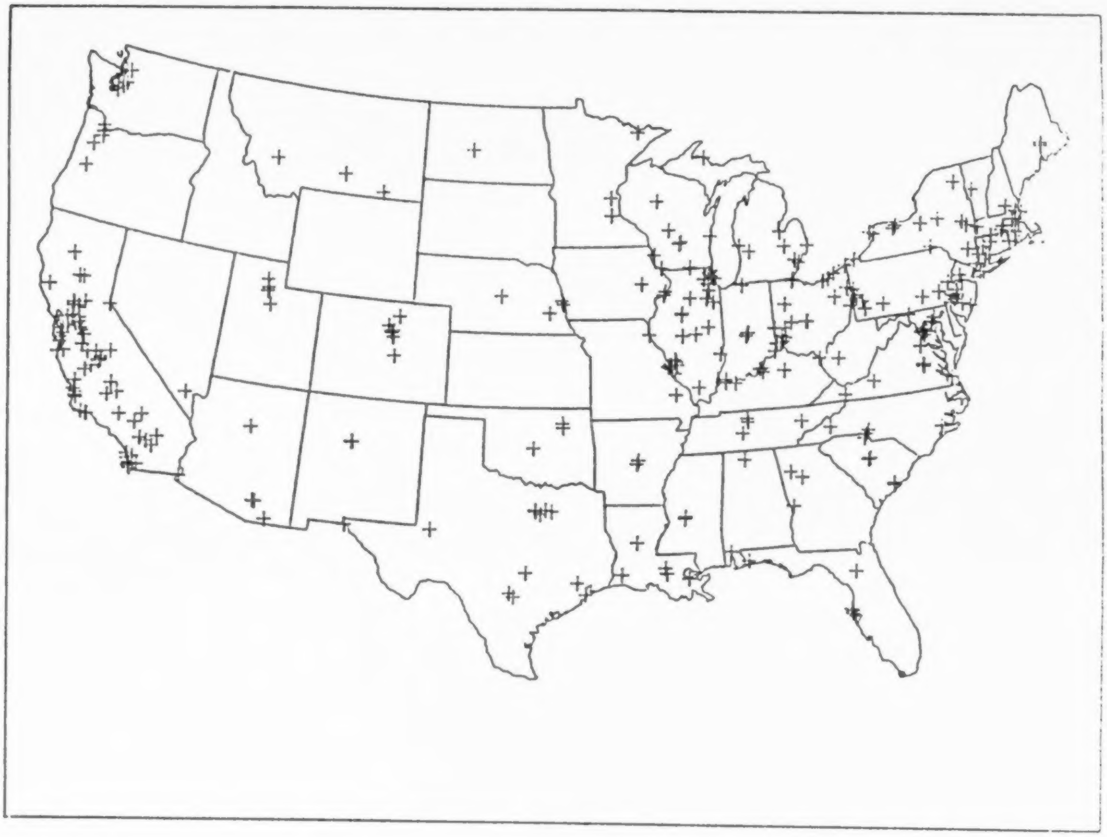


Figure 6.3.1. 1979 monitoring sites used in the analysis.

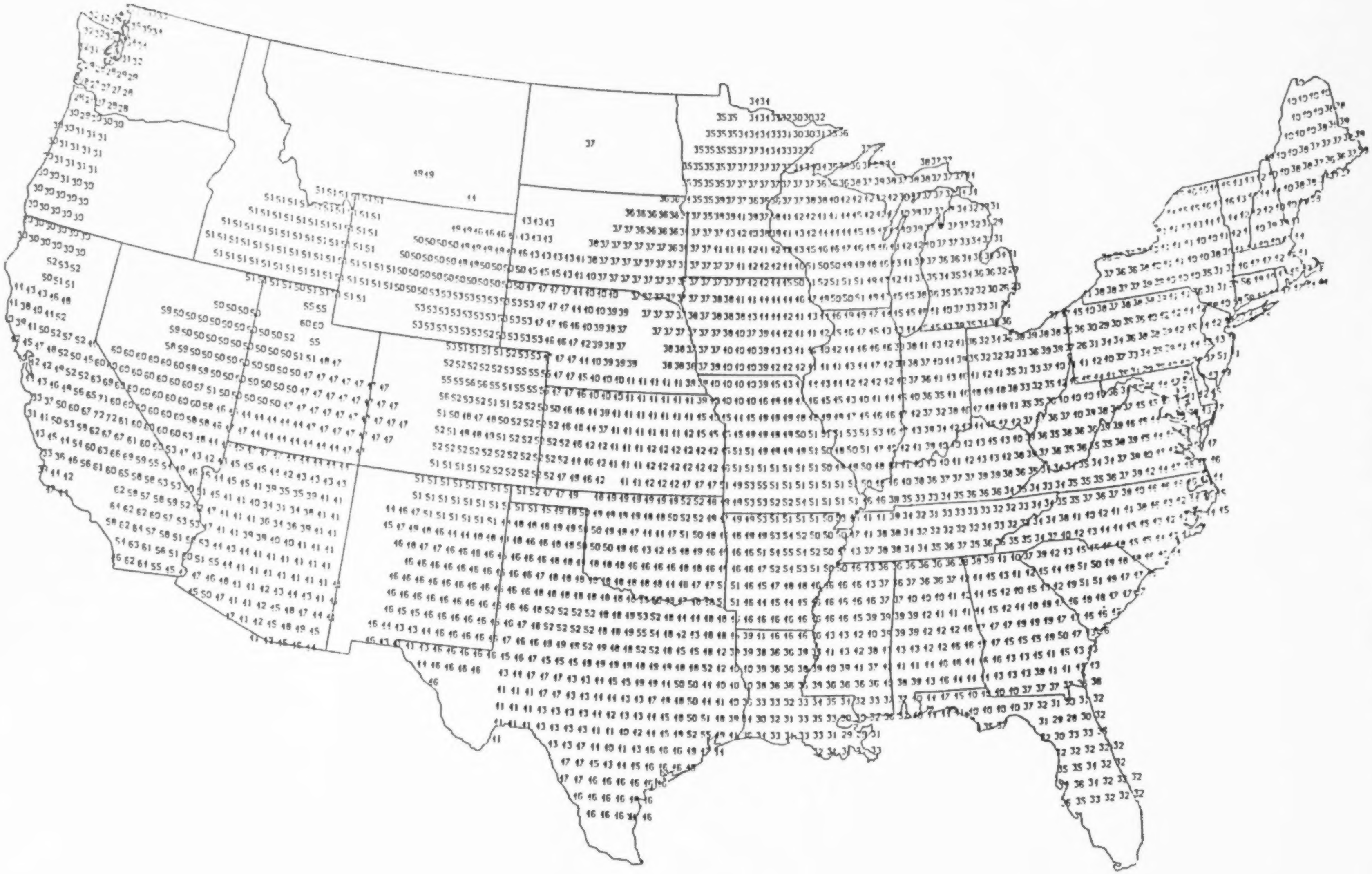


Figure 6.3.2. May - September, 1979 7-hr O_3 estimates (ppb), Original Model. Note. Blank areas indicate that no O_3 estimate was made due to insufficient data.

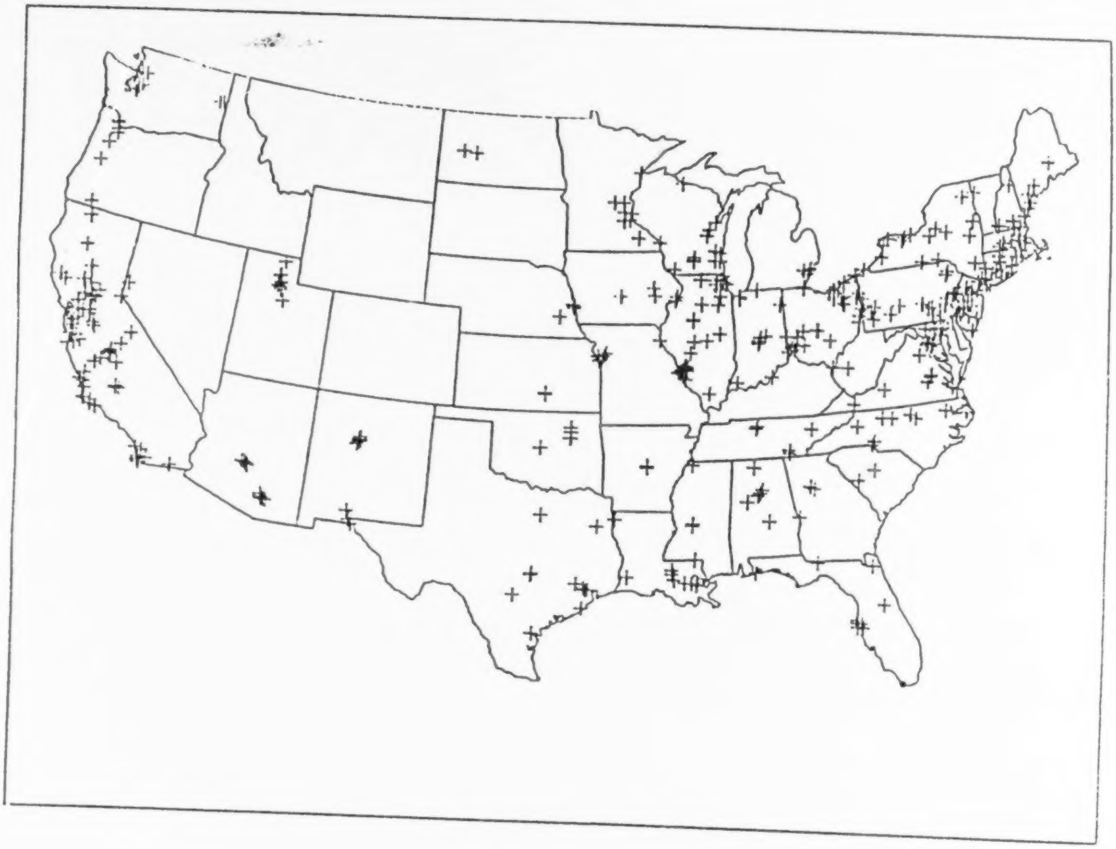


Figure 6.3.3. 1982 monitoring sites used in the analysis.

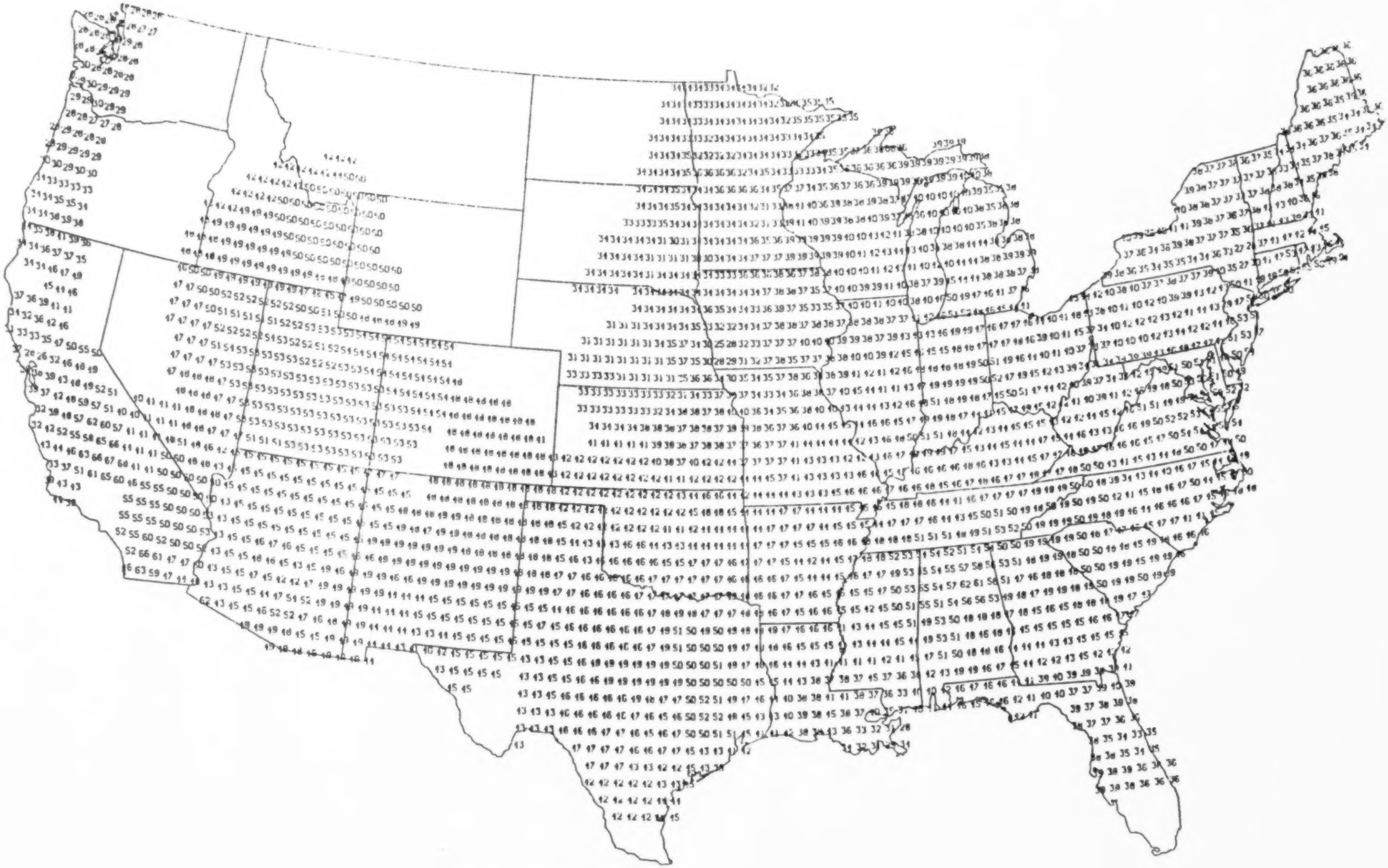


Figure 6.3.4. May - September, 1982 7-hr O_3 estimates (ppb), Original Model. Note. Blank areas indicate that no O_3 estimate was made due to insufficient data.

1982 Variogram Model

$$\gamma(h) = 27.2 + 0.362\ (h) \text{ for h less than 106 km.}$$
$$= 65.5 \text{ for h greater than 106 km.}$$

6.4. RESULTS

6.4.1. Comparison of the 'Corrected Model' to the 'Original Model'

Using the corrected kriging program and the original data, 'new' 7-hr, 5- month O_3 concentration estimates were calculated for the entire United States for 1979 and 1982 (Figures 6.4.1. and 6.4.2.). The blank areas indicate that no estimate was made due to insufficient data. A cell by cell comparison was made to compare the results derived from the Corrected Model to the Original Model. The difference between the estimates for each ½° x ½° cell was calculated. Statistics of the differences are provided (Table 6.4.1.). Table 6.4.1. shows that the overall mean value of each model is about the same for each year. The differences on a cell-by-cell basis were also predominantly small. Over 89% of the differences in 1979 were less than 1 ppb; in 1982, 85% were within 1 ppb. Using the 1979 data, the mean of the differences of the original model minus the corrected was -0.2 ppb. Using the 1982 data, the mean of the differences was 0 ppb.

Plots illustrating the differences are shown in Figures 6.4.3. and 6.4.4. (1979 and 1982 results, respectively). Only differences 1 ppb or greater are plotted on the maps. A positive difference means that the Original Model's estimate is higher than the Corrected Model's estimate. The general agreement between the models is to be expected. Only in areas where the monitoring sites display large differences in O_3 levels is there likely to be much observable difference between the models. One such area is shown in Figure 6.4.5. and illustrates the variation of 7-hr O_3 levels for several monitoring sites in the southeast corner of New York. The figure shows a cell (Longitude 74.25 West and Latitude 41.75 North) and the location of the five nearest monitoring sites used in the kriging of the cell. For each site, the site identification, the O_3 level (Z) and the kriging weight (Wt) are plotted. In this figure, the kriging weights shown are derived using the corrected kriging program. The closest site to the cell has a 7-hr seasonal O_3 concentration of 21.6 ppb and the other sites have values ranging from 42.8 to 56.6 ppb. Table 6.4.2. shows a comparison between the weights calculated for this cell using the original and corrected program. The large difference in kriged estimate for the cell is due to the different weights applied to the closest monitoring site. If all the monitoring sites had approximately the same O_3 values, then the kriged estimates would have been similar.

In conclusion, based upon the analyses described in this section, the error in the kriging program used by the NCLAN program in 1982 did not cause appreciable errors in the resulting O_3 7-hr seasonal estimates.

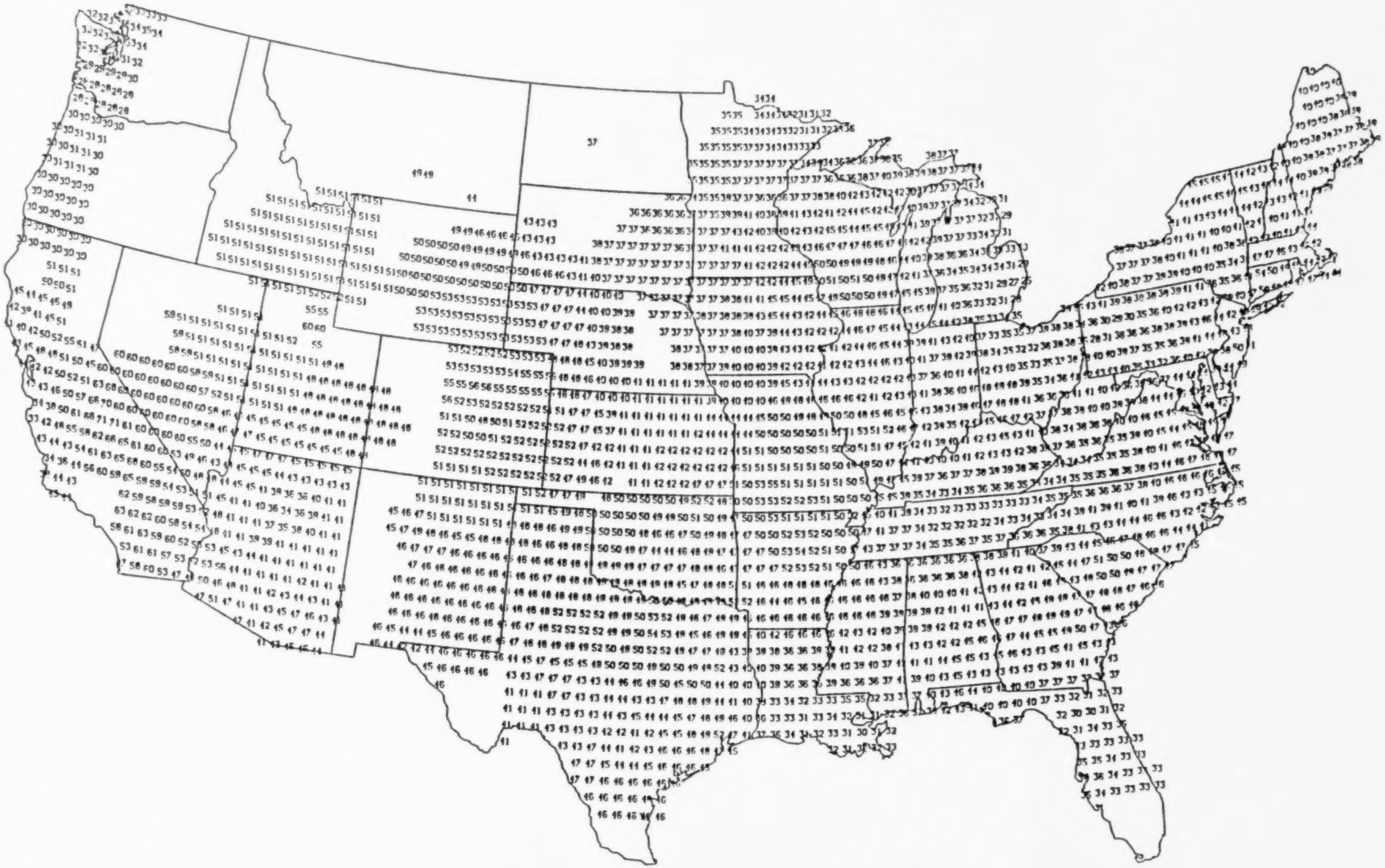


Figure 6.4.1. May - September, 1979 7-hr O_3 estimates (ppb), Corrected Model. Note. Blank areas indicate that no O_3 estimate was made due to insufficient data.

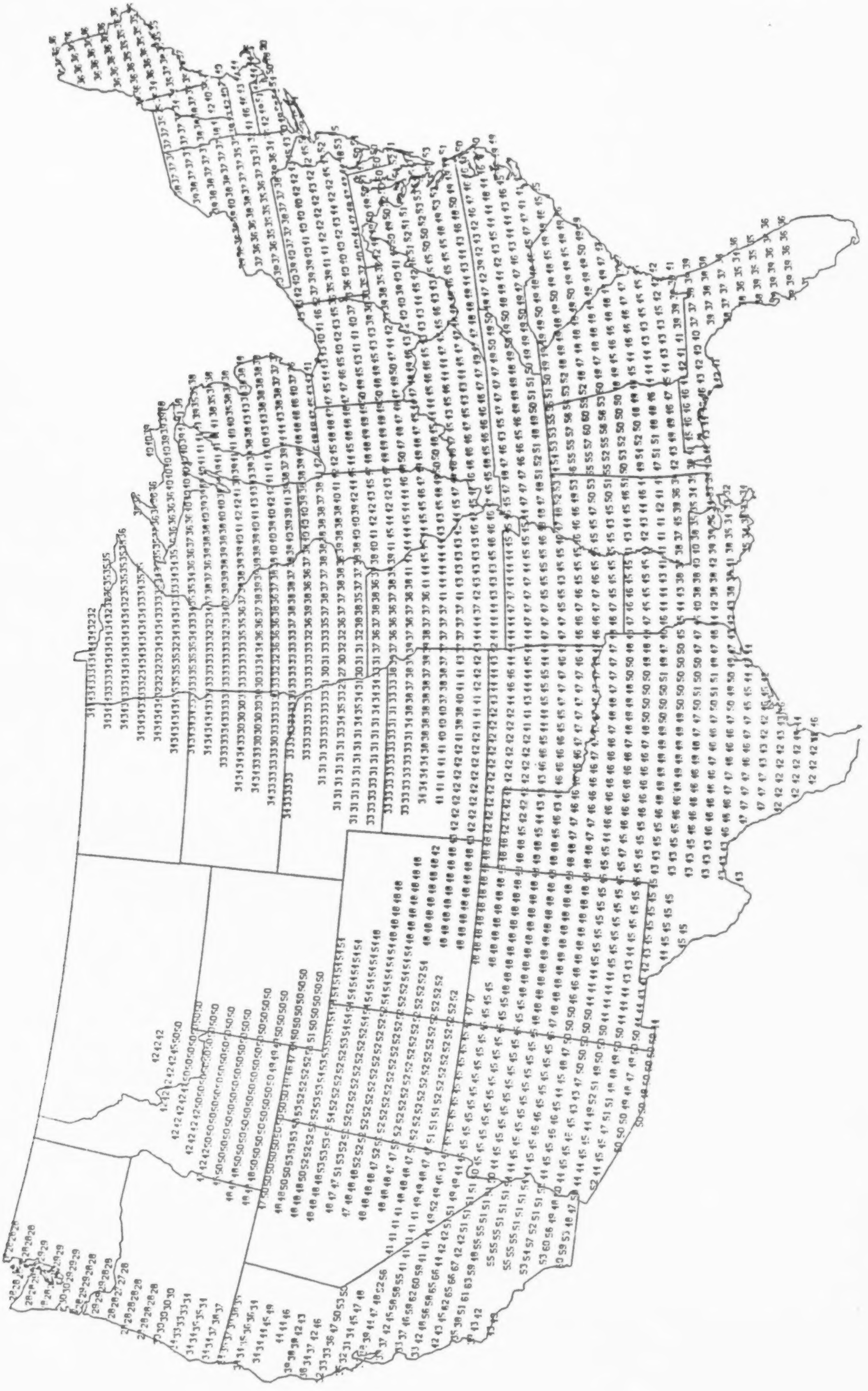


Figure 6.4.2. May - September, 1982 7-hr O_3 estimates (ppb), Corrected Model. Note. Blank areas indicate that no O_3 estimate was made due to insufficient data.

Table 6.4.1. The statistics comparing the original model and corrected model.

	1979		1982	
	Orig. Model	Corr. Model	Orig. Model	Corr. Model
Mean	43.4 ppb	43.6 ppb	43.2 ppb	43.2 ppb
Std. Dev.	6.95 ppb	6.88 ppb	6.65 ppb	6.60 ppb
No. of Cells	2684	2684	2727	2727
Differences				
	(Orig. Model - Corr. Model)		(Orig. Model - Corr. Model)	
Mean	-0.2 ppb		-0.0 ppb	
Std. Dev.	0.63 ppb		0.88 ppb	
% of differences within 1 ppb	89%		85%	

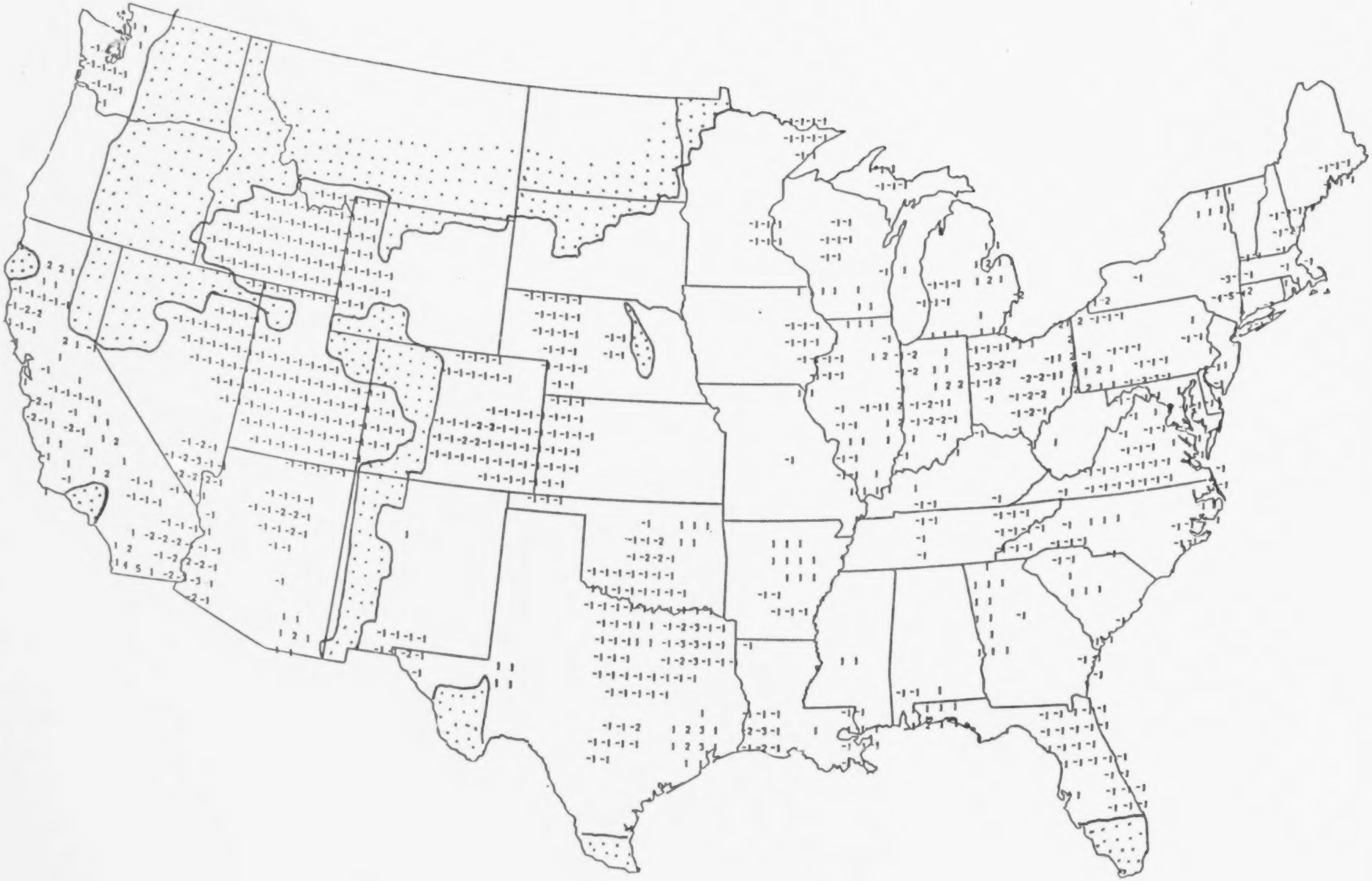


Figure 6.4.3. Cell by cell differences between the Original Model and Corrected Model (ppb), 1979. Note. Only cells where the two models differ by 1 ppb or more are plotted. A positive difference means the original model's estimate is higher than the corrected model's estimate. Those areas covered with dots were not kriged.

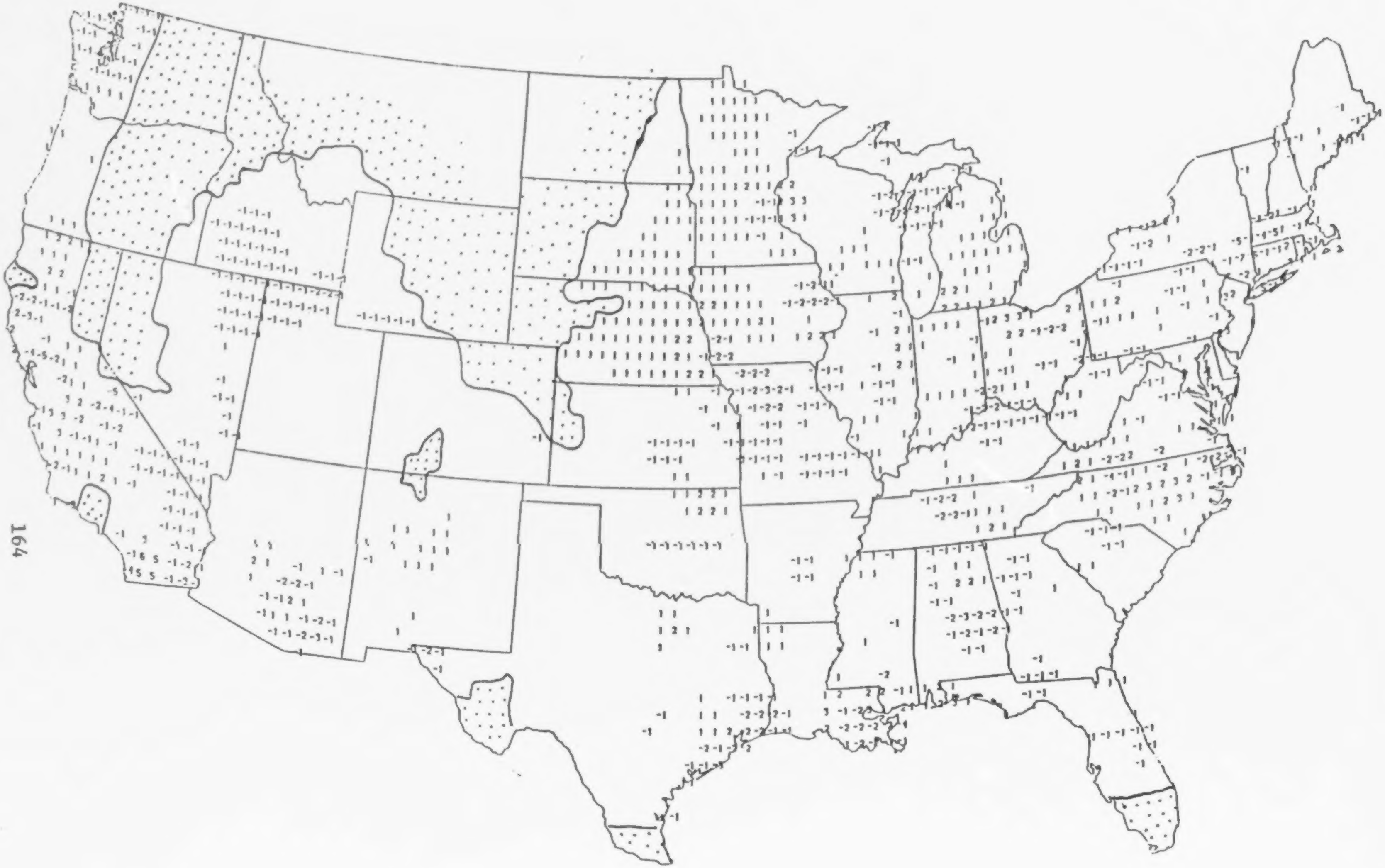


Figure 6.4.4. Cell by cell differences between the Original Model and Corrected Model (ppb), 1982. Note. Only cells where the two models differ by 1 ppb or more O_3 are plotted. A positive difference means the original model's estimate is higher than the corrected model's estimate. Those areas covered with dots were not kriged.

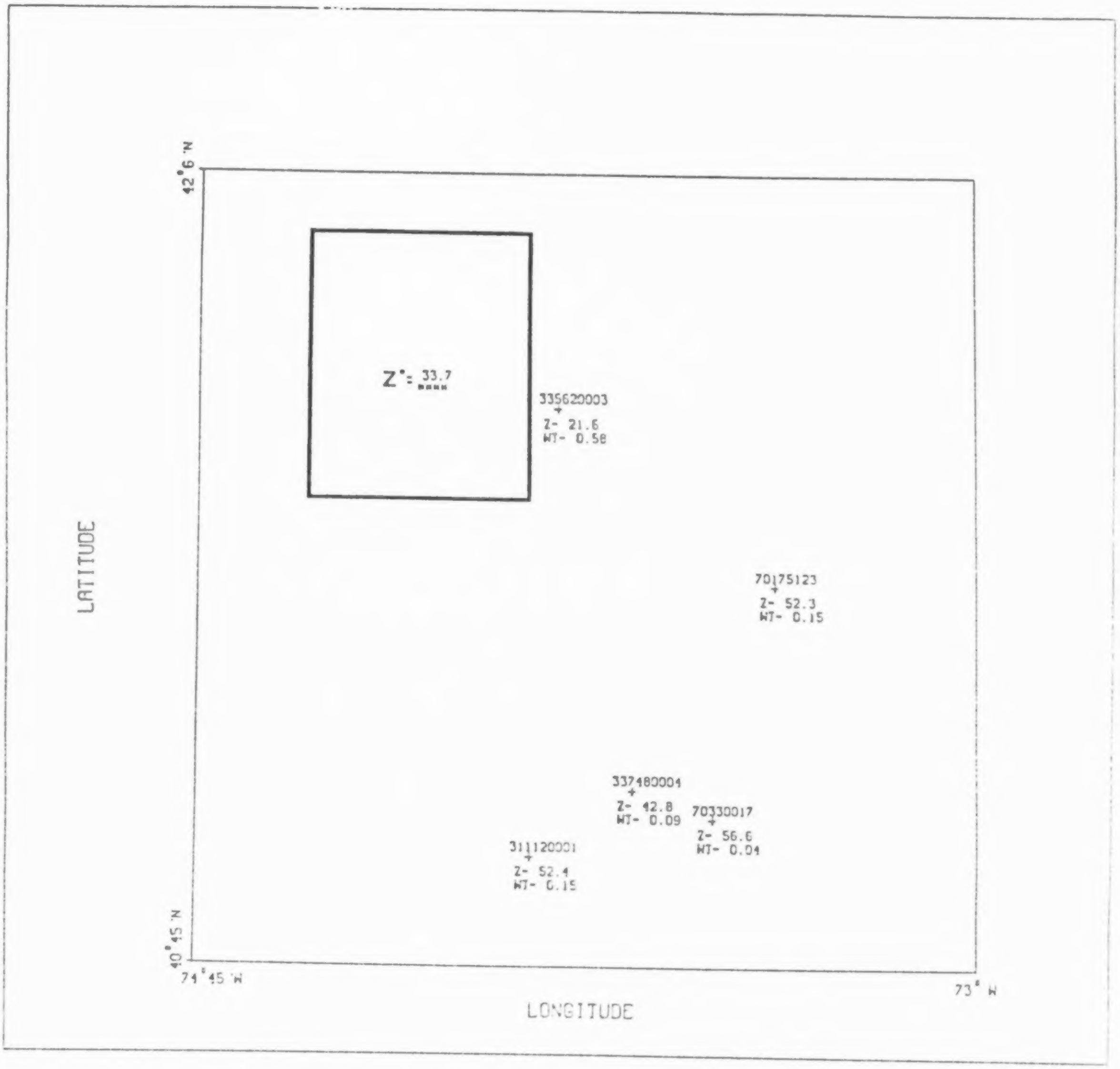

42°6'N
Z* = 33.7
335620003
Z- 21.6
WT- 0.58
LATITUDE
70175123
Z- 52.3
WT- 0.15
337480004
Z- 42.8
WT- 0.09
70330017
Z- 56.6
WT- 0.04
311120001
Z- 52.4
WT- 0.15
40°45'N
74°45'W
73°W
LONGITUDE

Figure 6.4.5. The location and 7-hr concentrations of the 5 nearest neighbors used in kriging a New York cell, (Z in units of ppb).

Table 6.4.2. Estimating a cell in New York using the corrected and original models.

```
                    Corrected Model Estimate

               Site =  74.25000W      41.75000N

Kriging Solution
Site Id       Latitude  Longitude  Value(ppb) Krig Wt.
******************************************************
335620003     41.7042   -73.9350      21.6     0.5828
070175123     41.4014   -73.4447      52.3     0.1450
337480004     41.0522   -73.7642      42.8     0.0917
311120001     40.9378   -73.9950      52.4     0.1454
070330017     41.0036   -73.5853      56.6     0.0351

    The Kriged Value for this Site =    33.70 ppb
       Kriging 95% Error Bound =     7.80 ppb

                    Original Model Estimate


Kriging Solution
Site Id       Latitude  Longitude Value(ppb) Krig Wt.
*****************************************************
335620003     41.7042   -73.9350     21.6        0.8132
070175123     41.4014   -73.4447     52.3        0.0272
337480004     41.0522   -73.7642     42.8        0.0333
311120001     40.9378   -73.9950     52.4        0.1592
070330017     41.0036   -73.5853     56.6       -0.0329

    The Kriged Average for this Site =    26.89 ppb
          Kriging 95% Error Bound =     7.01 ppb
```

6.4.2. The Effects of Exclusion of Certain Urban Data

In the original study, certain city-center data, because of depressed O_3 levels, were eliminated from the data base. Table 6.4.3. lists the geographic locations of the monitoring sites removed. Figure 6.4.6. shows the location of the city-center sites originally excluded from the 1979 and 1982 data bases by the NCLAN investigator. To determine the effect of removal of these sites on the kriged estimates, the excluded sites were added back into the data base. Using the previously excluded data, new kriged estimates were prepared for 1979 and 1982. The model for each of the years is referred to as the 'City-Center Inclusion Model'.

To determine the differences between the models and therefore, the effect of exclusion of city-center data, the results from the 'City-Center Inclusion Model' were compared to the results from the 'Corrected Model'. Figures 6.4.7. and 6.4.8. illustrate the cell-by-cell differences. Only differences greater than 1 ppb are plotted. A negative cell difference indicates that the estimate was lowered when the city-center data was added back into the data base. The maps show that including monitoring data from city-center sites depresses the estimated 7-hr seasonal O_3 levels in the vicinity of city-centers (except in Texas).

Statistics showing the differences are listed in Table 6.4.4. Overall, by including the previously excluded city-center data, the average O_3 value was reduced by approximately 0.16 ppb and 0.03 ppb in 1979 and 1982, respectively. The only appreciably reduced estimates were the cells near the excluded city- center monitoring sites.

In conclusion, the analysis shows that the inclusion of formerly excluded city-center data does depress the 7-hr seasonal O_3 estimates for those rural sites close to the city-center sites.

6.4.3. Regional Variogram Calculations for 1979 and 1982

To determine the spatial characteristics of O_3 across the United States and in particular, whether the characteristics differ from one section of the country to another, variograms and statistics were calculated for several partitions of the United States. The partitions were chosen primarily to determine if O_3 has distinctly different characteristics on the West Coast than it does in the rest of the United States. In addition, the question of whether the Northeast has different characteristics from the remainder of the country was explored. The data used in this analysis were the same as were used in the 1982 NCLAN study. The partitions studied were

1) The entire United States (except Alaska and Hawaii), all data were used;

2) data along the West Coast, this includes all monitoring sites west of 114 longitude (The Arizona California border);

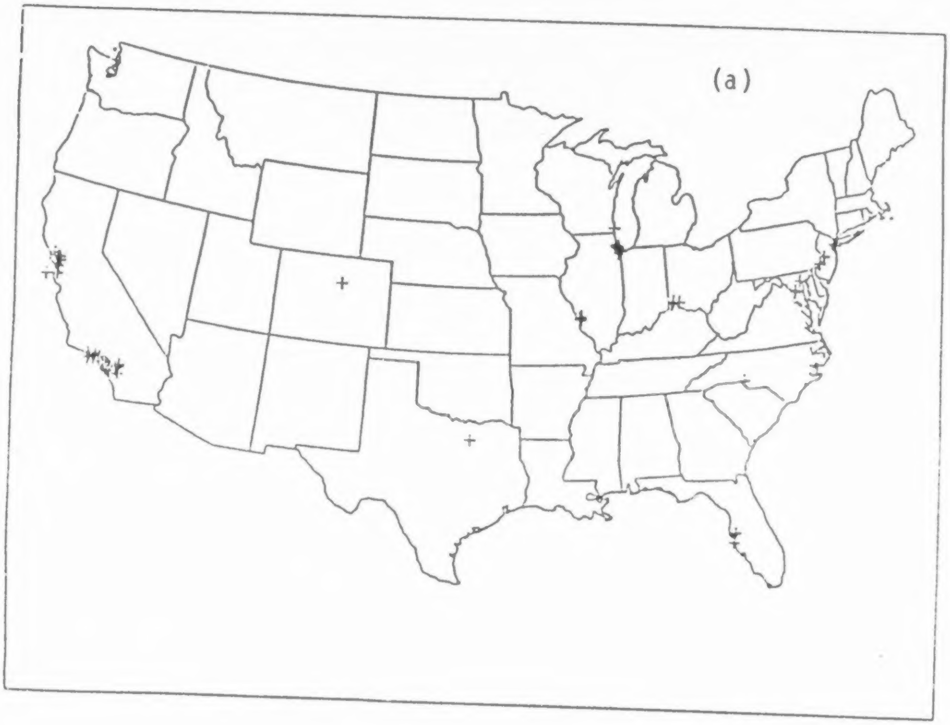
3) all data east of 114° longitude;

Table 6.4.3. The geographic areas in which monitoring station data were excluded.

Geographic Area	Latitude		Longitude	
	Min	Max	Min	Max
Los Angeles, CA	N33.5	N34.5	117.0W	119.5W
San Francisco, CA	36.5	38.5	122.0	123.5
St. Louis, MO	38.6	38.8	90.2	90.3
Chicago, IL	41.5	42.0	87.4	87.9
Philadelphia, PA	39.9	40.1	75.1	75.2
Phoenix, AZ*	33.0	34.0	111.5	112.5
Denver, CO*	39.5	40.0	104.5	105.5
Albuquerque, NM*	35.0	35.5	106.0	107.0
Dallas-Ft. Worth, TX*	32.5	33.0	96.5	97.5
St. Louis, MO*	38.5	39.0	90.0	90.5
Chicago, IL*	41.5	42.0	87.0	88.0
Chicago, IL*	42.5	43.5	87.5	88.0
Charlotte, NC*	34.5	35.5	80.5	81.5
Cincinnati, OH*	38.5	39.5	84.0	85.0
Washington, DC*	38.5	39.5	76.5	77.5
Philadelphia, PA*	39.5	40.5	75.4	75.5
New York NY*	40.5	41.0	73.5	74.5
Tampa, FL*	27.0	38.5	82.0	83.0
Boston, MA*	42.0	42.5	70.5	71.5

* City-Center data excluded from these locations.

Adopted from Heck et al. (41).



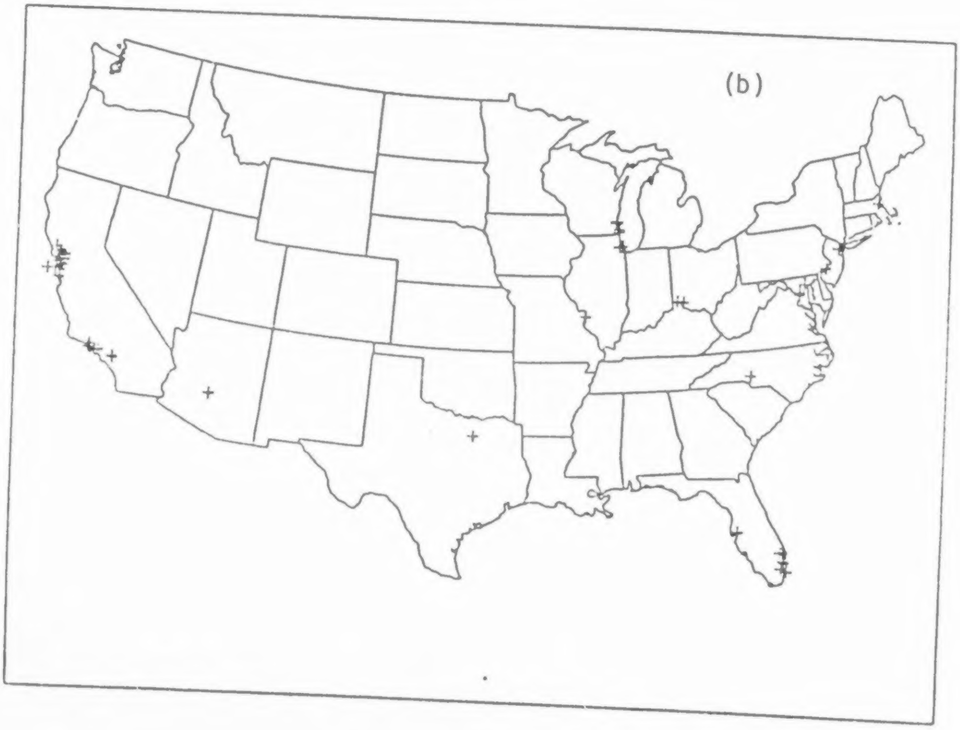


Figure 6.4.6. City Center monitoring sites deleted from a) 1979; and b) 1982 O_3 data base.

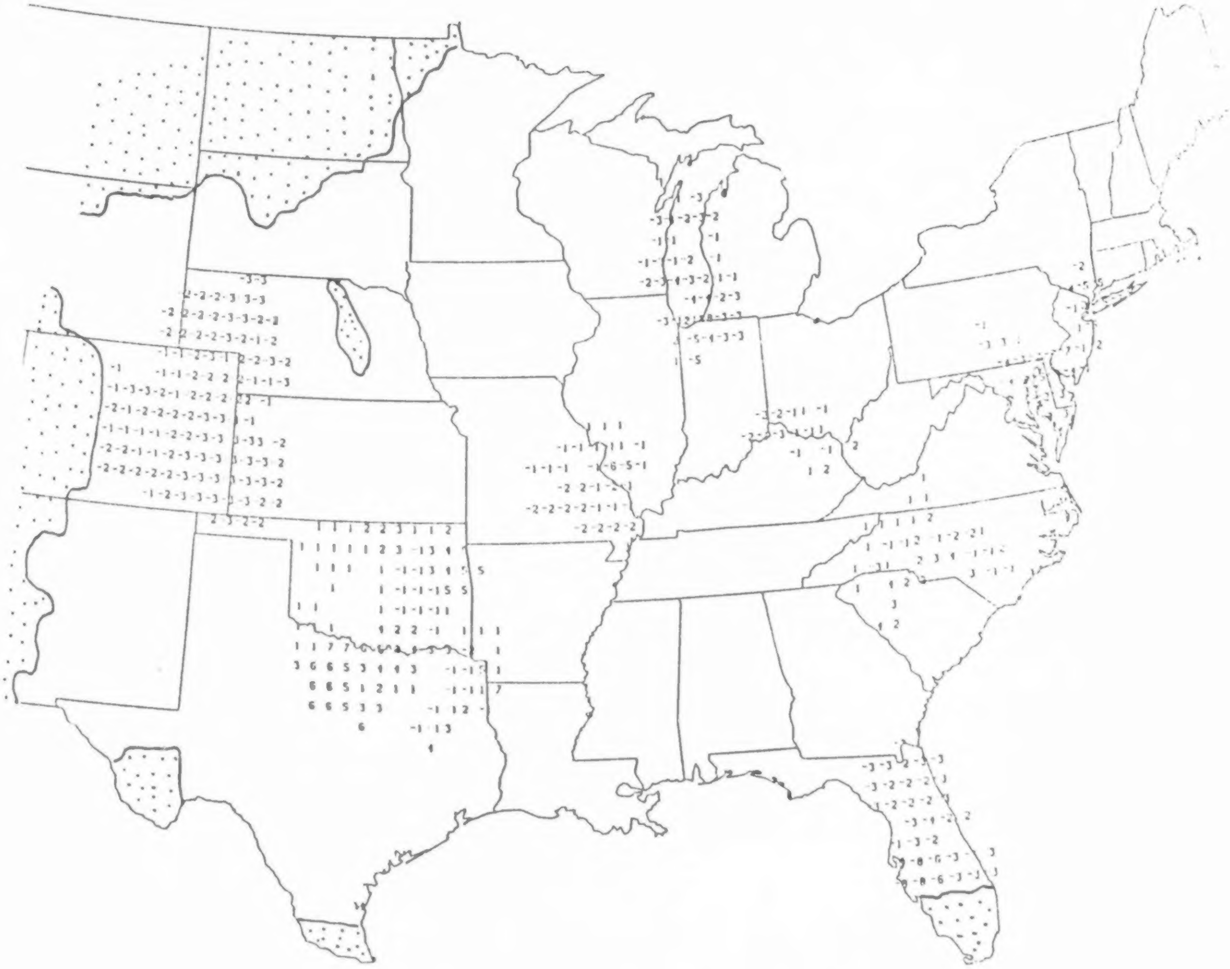


Figure 6.4.7. Cell by cell differences between the corrected model and City Center Inclusion Model (ppb), 1979. Note. Only cells where the two models differ by 1 ppb or more O_3 are plotted. A positive difference means the original model's estimate is higher than the corrected model's estimate. Those areas covered with dots were not kriged.

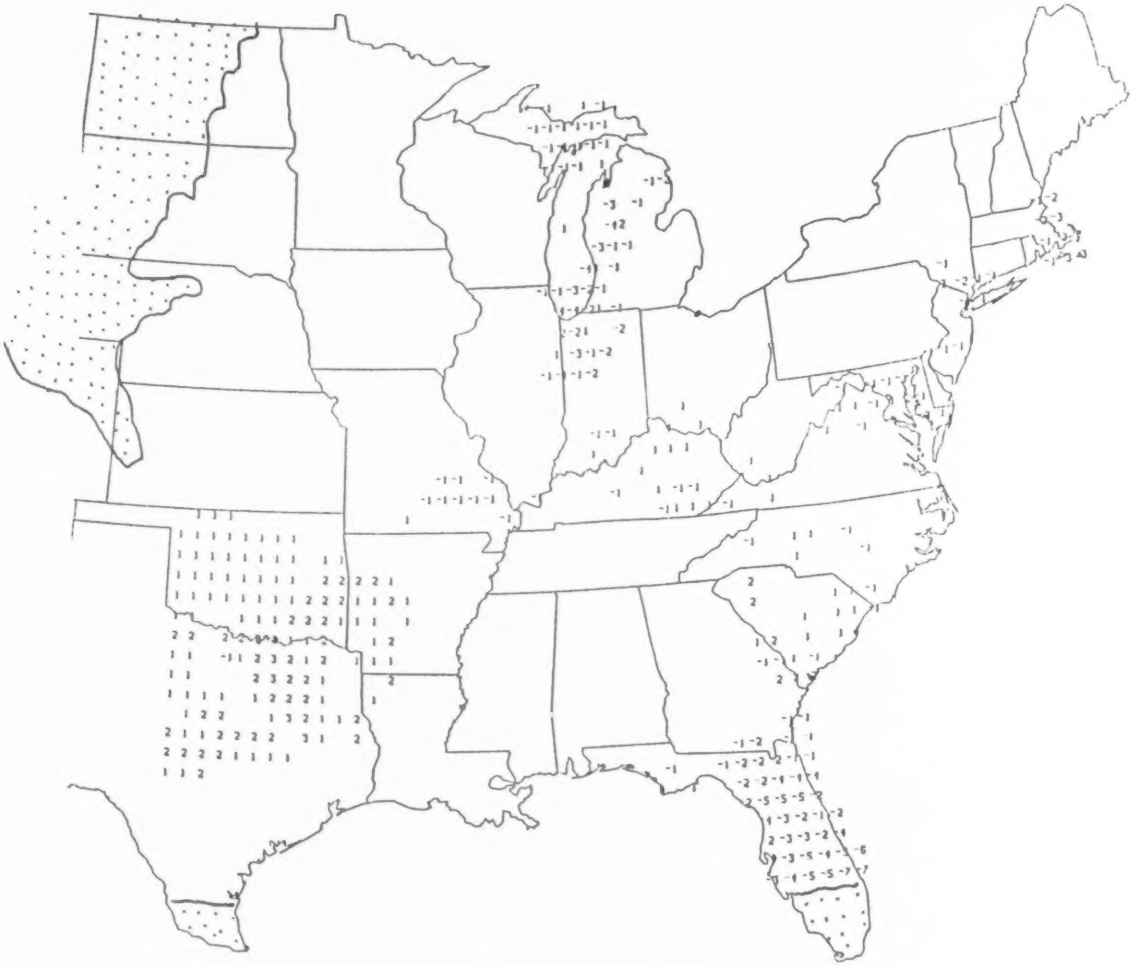


Figure 6.4.8. Cell by cell differences between Corrected Model and City Center Inclusion Model (ppb), 1982. Note. Only cells where the two models differ by 1 ppb or more O_3 are plotted. A positive difference means the original model's estimate is higher than the corrected model's estimate. Those areas covered with dots were not kriged.

Table 6.4.4. The differences between using the city-center inclusion model and the corrected model. The effect of excluding city-center data are quantified.

	1979	1982
	Differences	
Mean	-0.16 ppb	-0.03 ppb
Std. Dev.	1.20 ppb	0.80 ppb
# of Cells	2310	1743
% of differences within 1 ppb	86%	90%

4) data in the Northeastern United States (defined as being east of the Mississippi River and North of 37° latitude); and

5) data east of 114° but not in the Northeast United States.

Statistics of each of the 1979 data sets are given in Table 6.4.5. Variograms calculated for the data partitions are shown in Figure 6.4.9. The West Coast O_3 data (Figure 6.4.9.b) stand out as being different from the remainder of the United States (Figure 6.4.9.a). The variogram for the West Coast shows as much higher nugget effect, 80, compared to 35 for the rest of the United States. The combination of the higher variance and much different variogram values lead to the conclusion that 7-hr seasonal O_3 concentrations along the West Coast have different spatial characteristics than the remainder of the United States and should therefore, be studied and estimated separately. The variogram for the entire area east of 114° (Figure 6.4.9.c) looks similar to the variogram for the Northeast (Figure 15.a). There is little noticeable difference between the variogram for the entire area east of 114° and the Northeast partition. This similarity is due mainly to the fact that the Northeast partition contains two- thirds of monitoring data and virtually all of the closely spaced monitoring stations.

The variograms shown in Figures 6.4.9. and the statistics listed in Table 6.4.4. provide no evidence that the United States east of 114° should be further partitioned. Therefore, for this analysis, it was decided that one variogram would be used for the kriging estimates of the cells east of 114°.

A nested spherical model was fitted to the variogram of the data east of 114° and is shown on variogram Figure 6.4.9.c. The parameters of this model are

Nugget effect = 25.0 $(\text{ppb})^2$
C(1) = 32. Range(1) = 100. km
C(2) = 23. Range(2) = 650. km

Statistics of each of the 1982 data sets are given in Table 6.4.6. Variograms calculated for the data partitions are shown in Figure 6.4.10. The West Coast data, which includes California, Oregon, and Washington, have a much higher variance than the O_3 data from the rest of the United States (Figures 6.4.10.a,b,c). The different partitions for the remainder of the United States all have approximately the same mean and variance. A nested spherical model was fitted to the experimental variogram of the data east of 114° (Figure 6.4.10.d). The parameters of this model are

Nugget effect = 8.0 $(\text{ppb})^2$
C(1) = 15. Range(1) = 20. kilometers (km)
C(2) = 35. Range(2) = 135. km

Table 6.4.5. The statistics of 1979 O_3 data by region.

Entire United States

Mean = 44.2 ppb
Std. Dev. = 10.5 ppb
No. of
Samples = 316

All Data East of 114°

Mean = 42.8 ppb
Std. Dev. = 9.9 ppb
No. of
Samples = 244

West Coast Data

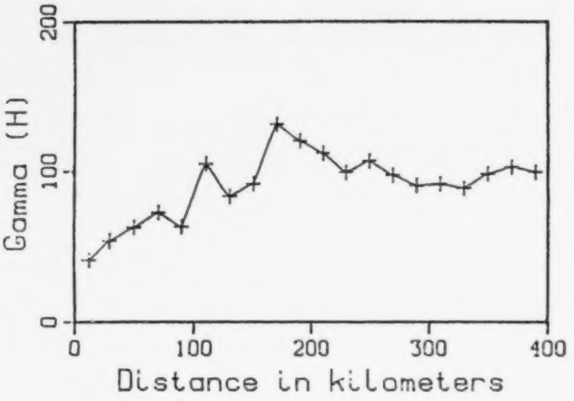
Mean = 48.5 ppb
Std. Dev. = 13.8 ppb
No. of
Samples = 72

Northeastern U.S.

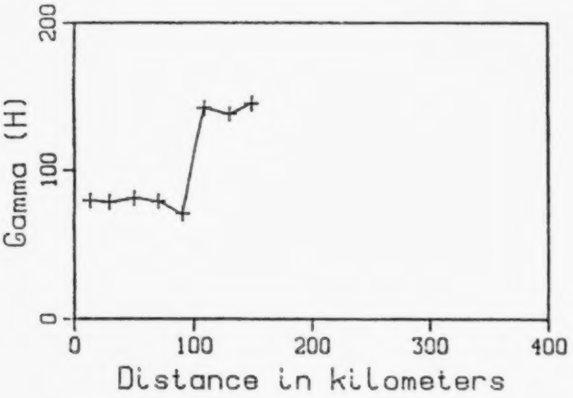
Mean = 42.3 ppb
Std. Dev. = 8.5 ppb
No. of
Samples = 165

Data East of 114° but
not included in Northeastern U.S.

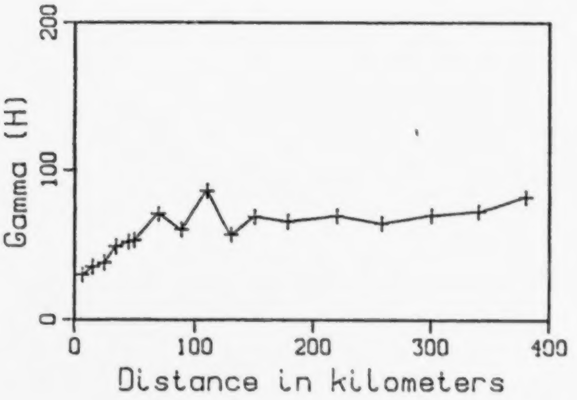
Mean = 44.1 ppb
Std. Dev = 9.81 ppb
No. of
Samples = 72



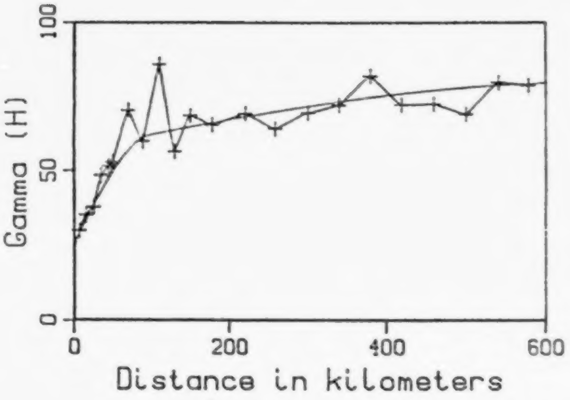
a. All 1979 data



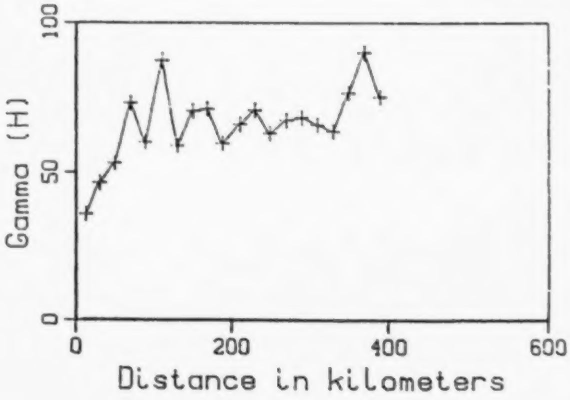
b. 1979 Westcoast data



c. 1979 data east of 114 Lat.



d. 1979 data east of 114 Lat.



e. 1979 data Northeast U.S.

Figure 6.4.9. Variograms calculated for the data partitions using 1979 SAROAD 7-hr concentrations.

Table 6.4.6. The statistics of 1982 O_3 data by region.

Entire United States

Mean = 43.4 ppb
Std. Dev. = 8.8 ppb
No. of
Samples = 401

All Data East of 114°

Mean = 43.4 ppb
Std. Dev. = 7.6 ppb
No. of
Samples = 325

West Coast Data

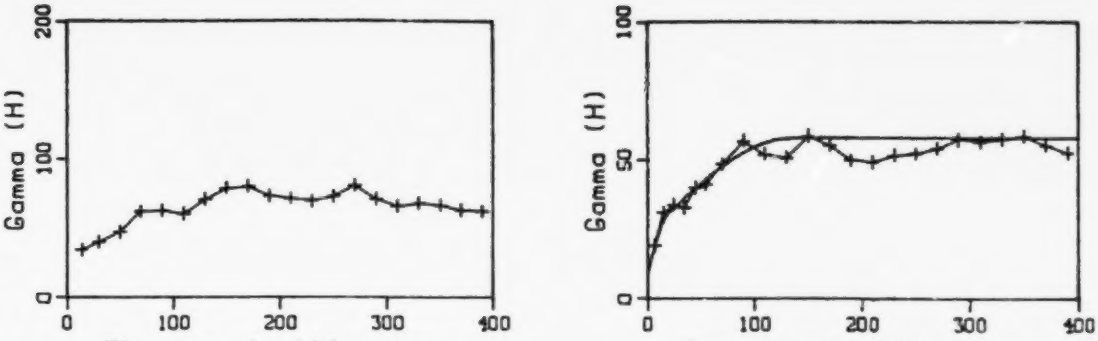
Mean = 43.2 ppb
Std. Dev. = 12.6 ppb
No. of
Samples = 76

Northeastern U.S.

Mean = 43.2 ppb
Std. Dev. = 7.4 ppb
No. of
Samples = 214

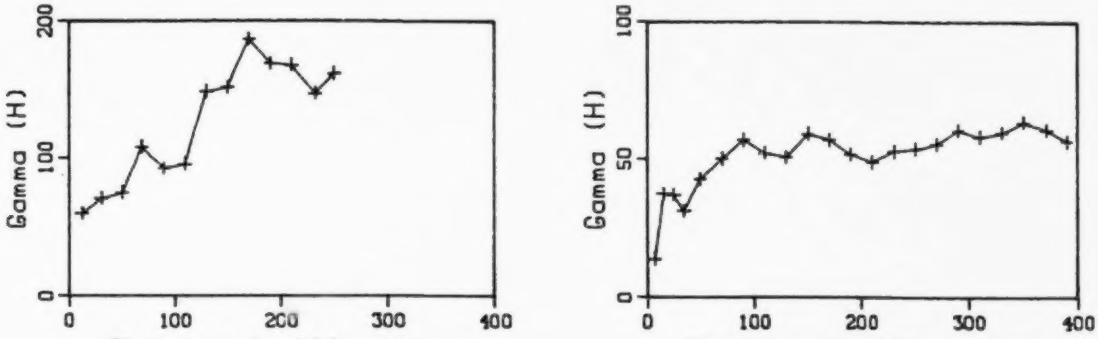
Data east of 114° but
not in Northeastern U.S.

Mean = 43.9 ppb
Std. Dev. = 8.1 ppb
No. of
Samples = 111



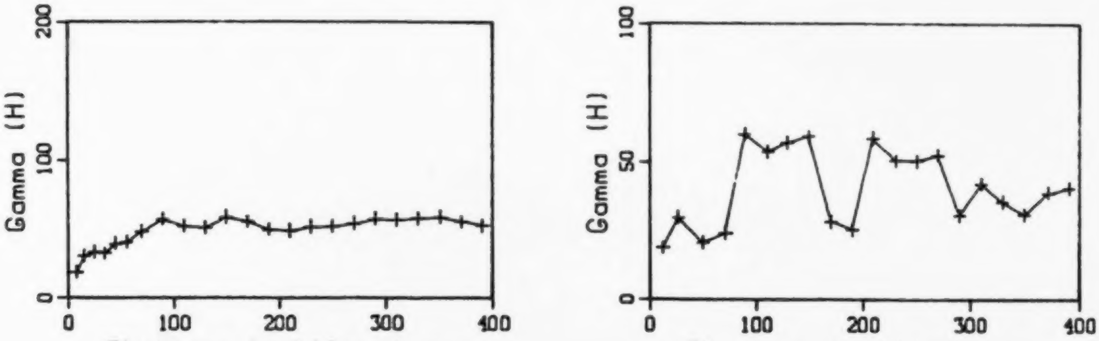
a. All 1982 data

d. 1982 data east of 114 Lat.



b. 1982 Westcoast data

e. 1982 data Northeast U.S.



c. 1982 data east of 114 Lat.

f. 1982 data excluding NE

Figure 6.4.10. Variograms calculated for the data partitions using 1982 SAROAD 7-hr concentrations.

The maximum range of influence of this model, 135 km, is slightly greater than the 106 km used in the original NCLAN study, while the nugget is substantially lower, 8, versus 27.2 in the NCLAN study.

The 1979 parameters that were calculated were different than the parameters used to model the 1982 variogram. The much higher nugget effect observed for the 1979 variogram when compared to the 1982 variogram suggests that the 1982 monitoring data may have been subject to fewer measurement errors than the 1979 data. In addition, there is a difference in the range of the two variograms. The reason for this observation is unclear.

6.4.4. Kriging of 1979 and 1982 O_3 Levels

In addition to the variogram model, several other parameters must be specified in the kriging run. Chief among these are the number of samples to use in the kriging of each cell and how these samples are selected. For this study, the maximum number of samples used in each estimation was limited to the nearest 10 samples within the search radius of the cell being estimated. Before a cell was estimated, at least three samples had to be within the search radius. A search radius of 250 km was used for the 1979 run and 200 km was used for the 1982 run. These parameters are different from those used in the original NCLAN study (nearest 5 samples within 500 km). It was believed that by allowing more samples to be used, the estimates would be improved for areas where many monitoring sites were nearby. However, using a smaller search radius resulted in some cells not being used that were originally included in the NCLAN Model.

Figures 6.4.11. and 6.4.12. are the resulting maps of O_3 estimates for 1979 and 1982, respectively using the ordinary kriging. The model for each year is referred to as the 'Ordinary Kriging Model'.

6.4.5. Comparison of the Ordinary Kriging Model with the NCLAN Models

The 'Ordinary Kriging Models' were compared to both the NCLAN 'Original Model' and the 'Corrected Model'. The comparison was limited to cells east of 100° longitude because the West Coast was excluded in the 'Ordinary Kriging Model'.

Table 6.4.7. shows statistics of the cell-by-cell difference between the models. The Ordinary Kriging Models are clearly different from the original NCLAN model. Only 40% of the cell estimates are within 1 ppb in 1979 and 48% in 1982. Compared to the Corrected model, the differences are 44% and 61%, in 1979 and 1982, respectively.

The differences are graphically shown in Figures 6.4.13. through 6.4.16. Only differences greater than or equal to 1 ppb were plotted. If the cell estimates were less than 1 ppb, the cell was left blank. The geographic areas where the largest differences between the three 1979 models were found in Pennsylvania and Arkansas. The Ordinary Kriging estimates were up to 11 ppb higher than the NCLAN estimates. The largest 1982 differences were found in Wisconsin, where the Ordinary Kriging estimates were up to 6 ppb higher than the EPA estimates.

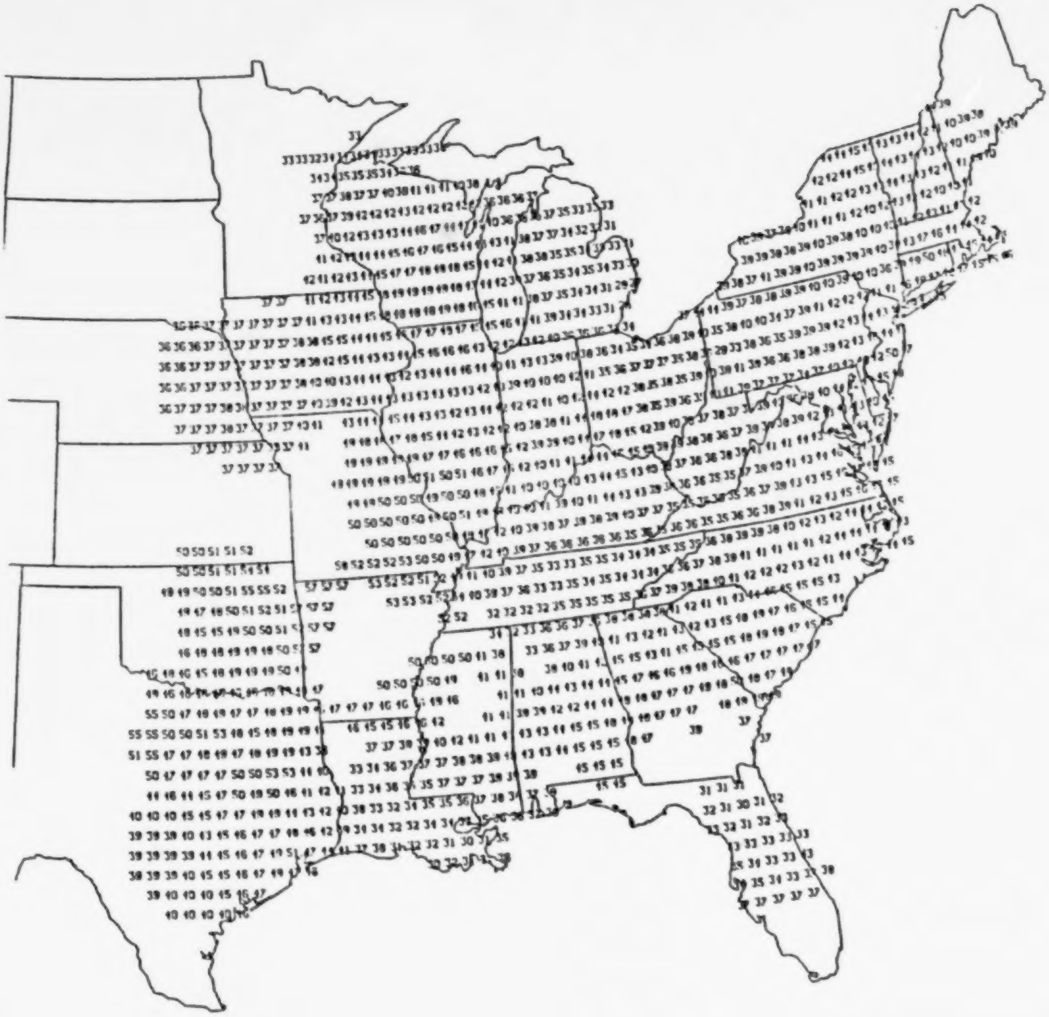


Figure 6.4.11. May - September, 1979 7-hr O_3 estimates (ppb), Ordinary Kriging Model. Note. Blank areas indicate that no ozone estimate was made due to insufficient data.

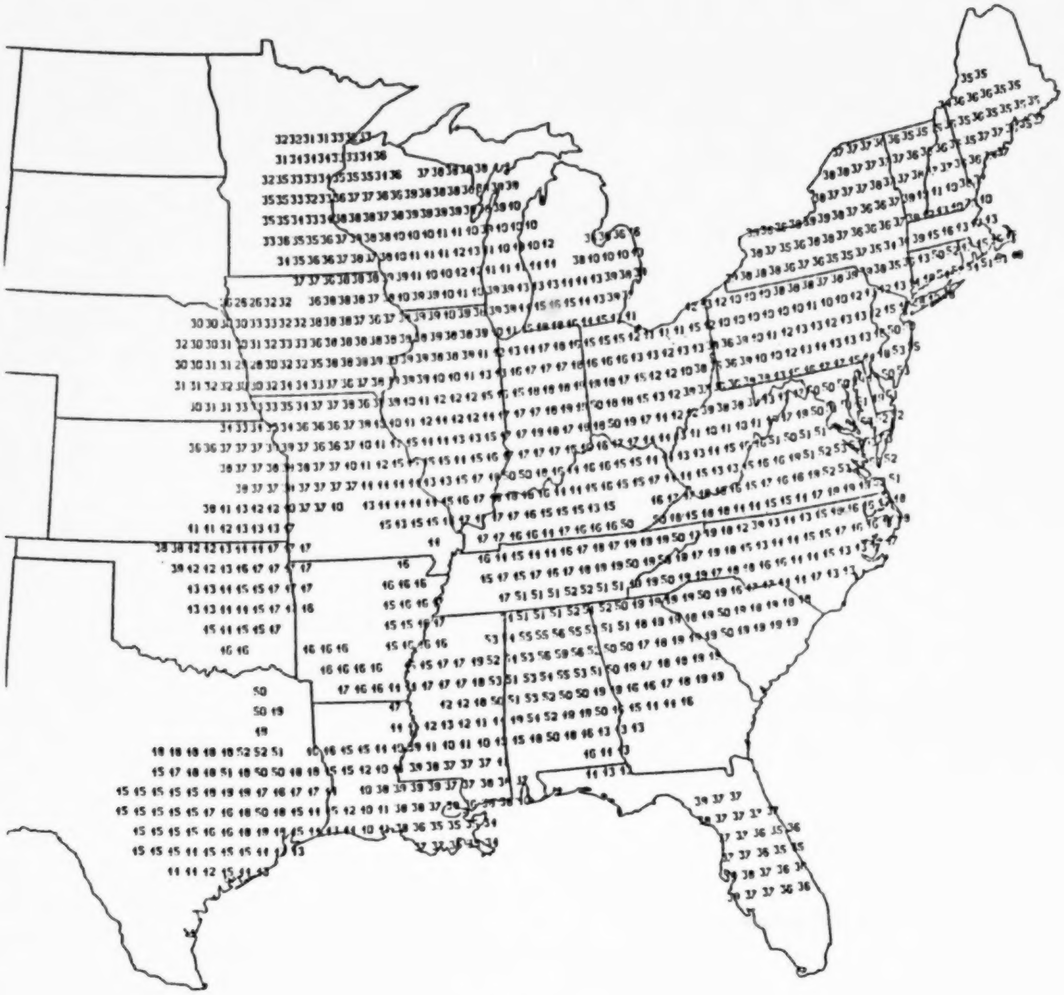


Figure 6.4.12. May - September, 1982 7-hr O_3 estimates (ppb). Ordinary Kriging Model. Note. Blank areas indicate that no O_3 estimate was made due to insufficient data.

Table 6.4.7. The comparison of ordinary kriging to NCLAN's original and corrected models.

	1979	1982
Original Model - Ordinary Kriging Model Differences		
Mean	= -0.18 ppb	= 0.10 ppb
Std. Dev.	= 2.49 ppb	= 1.84 ppb
Percent of Differences within 1 ppb	40 %	48 %
Corrected Model - Ordinary Kriging Model Differences		
Mean	= -0.14 ppb	= .14 ppb
Std. Dev.	= 2.32 ppb	= 1.46 ppb
Percent of Differences within 1 ppb	44%	61%

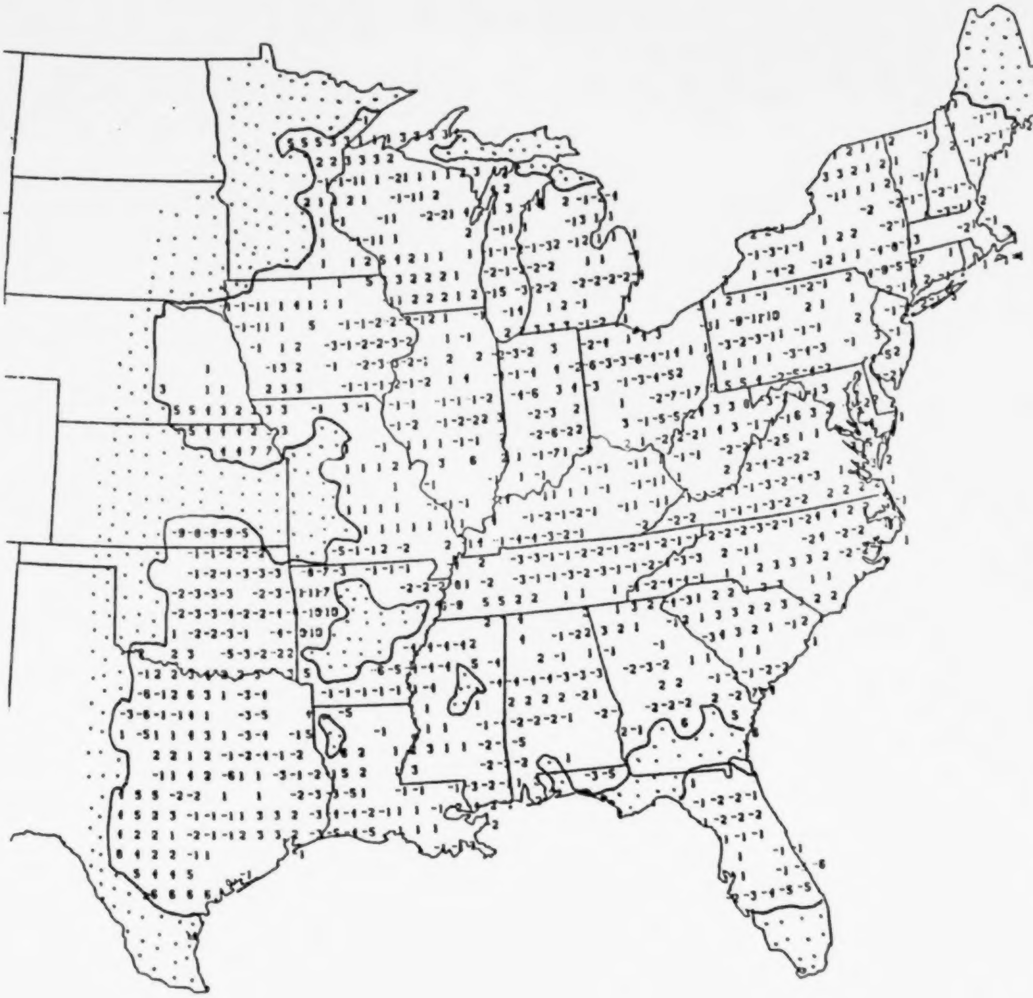


Figure 6.4.13. Cell by cell differences between Original Model and Ordinary Kriging Model (ppb), 1979. Note. Blank areas indicate that no ozone estimate was made due to insufficient data. Those areas covered with dots were not kriged.

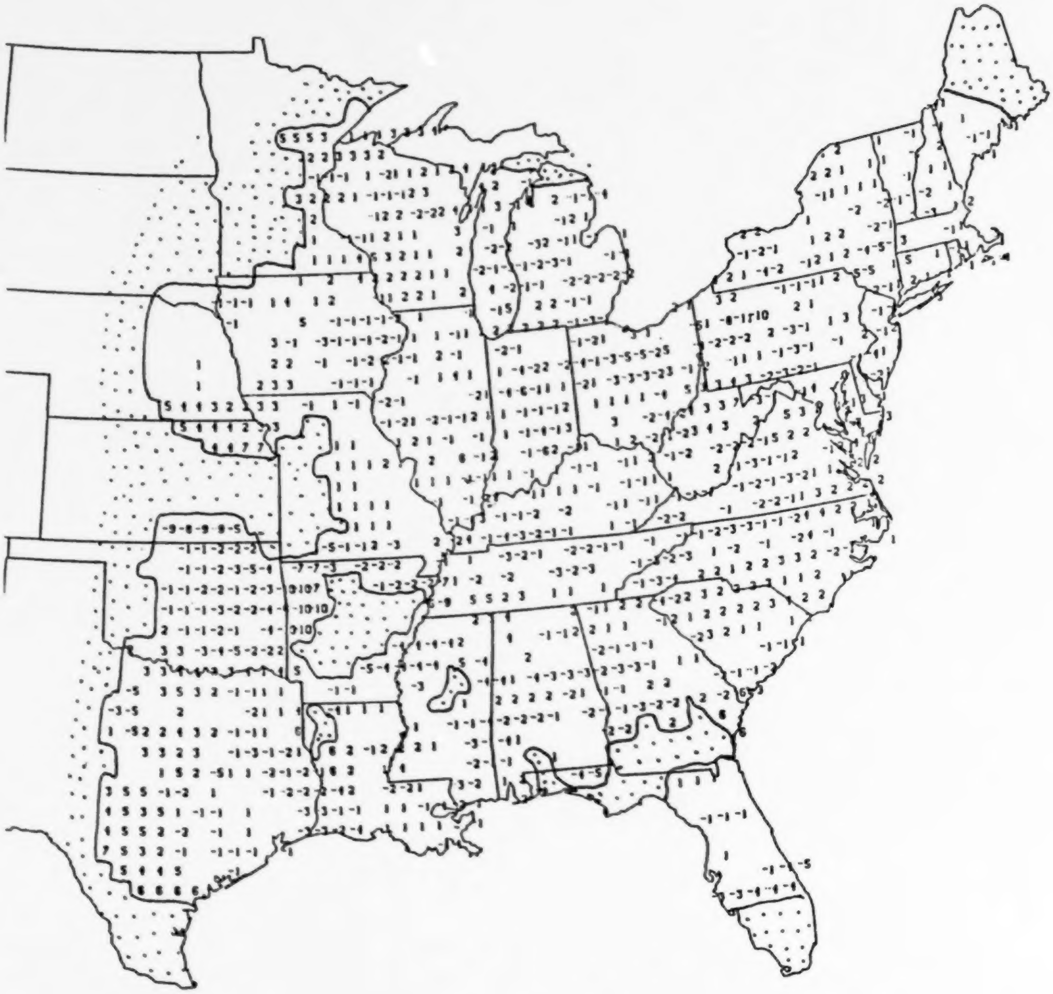


Figure 6.4.14. Cell by cell differences between Corrected Model and Ordinary Kriging Model (ppb), 1979. Note. Blank areas indicate that no ozone estimate was made due to insufficient data. Those areas covered with dots were not kriged.

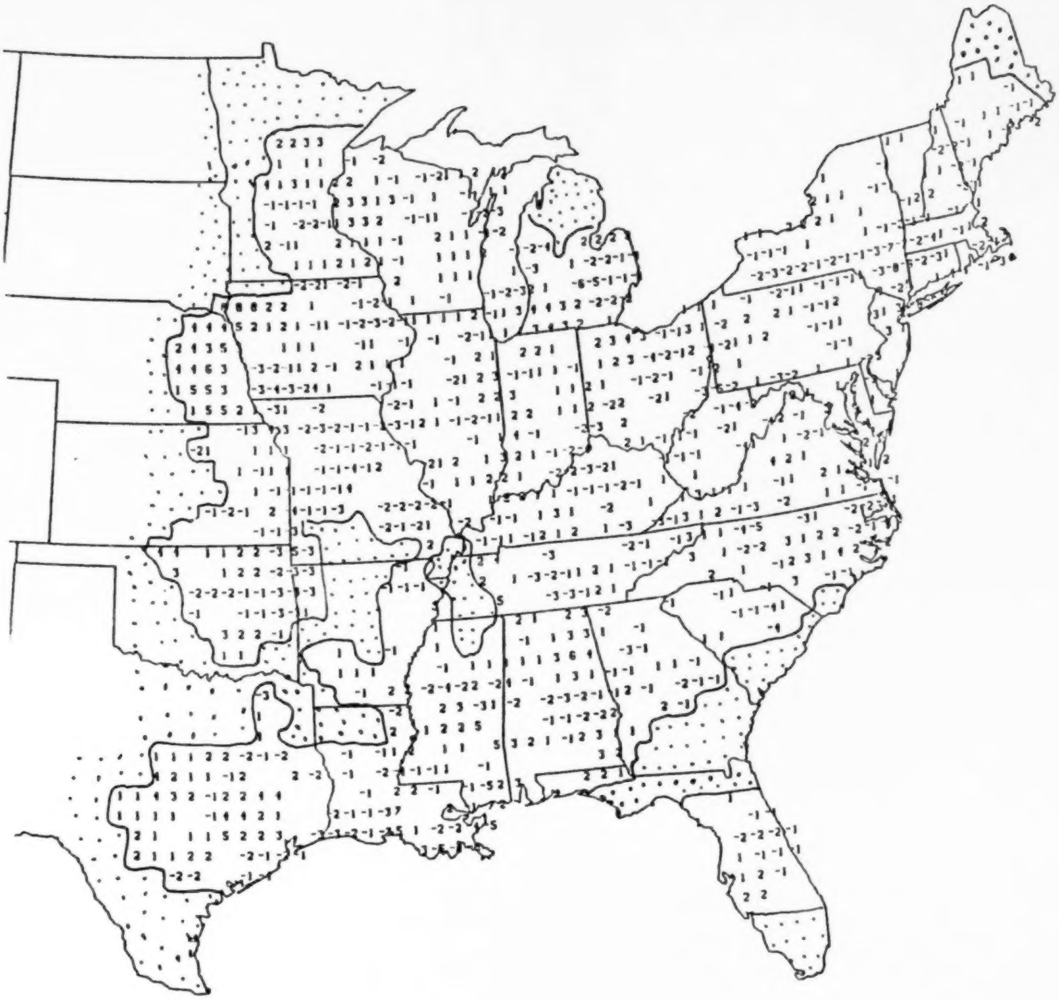


Figure 6.4.15. Cell by cell differences between Original Model and Ordinary Kriging Model (ppb), 1982. Note. Blank areas indicate that no ozone estimate was made due to insufficient data. Those areas covered with dots were not kriged.

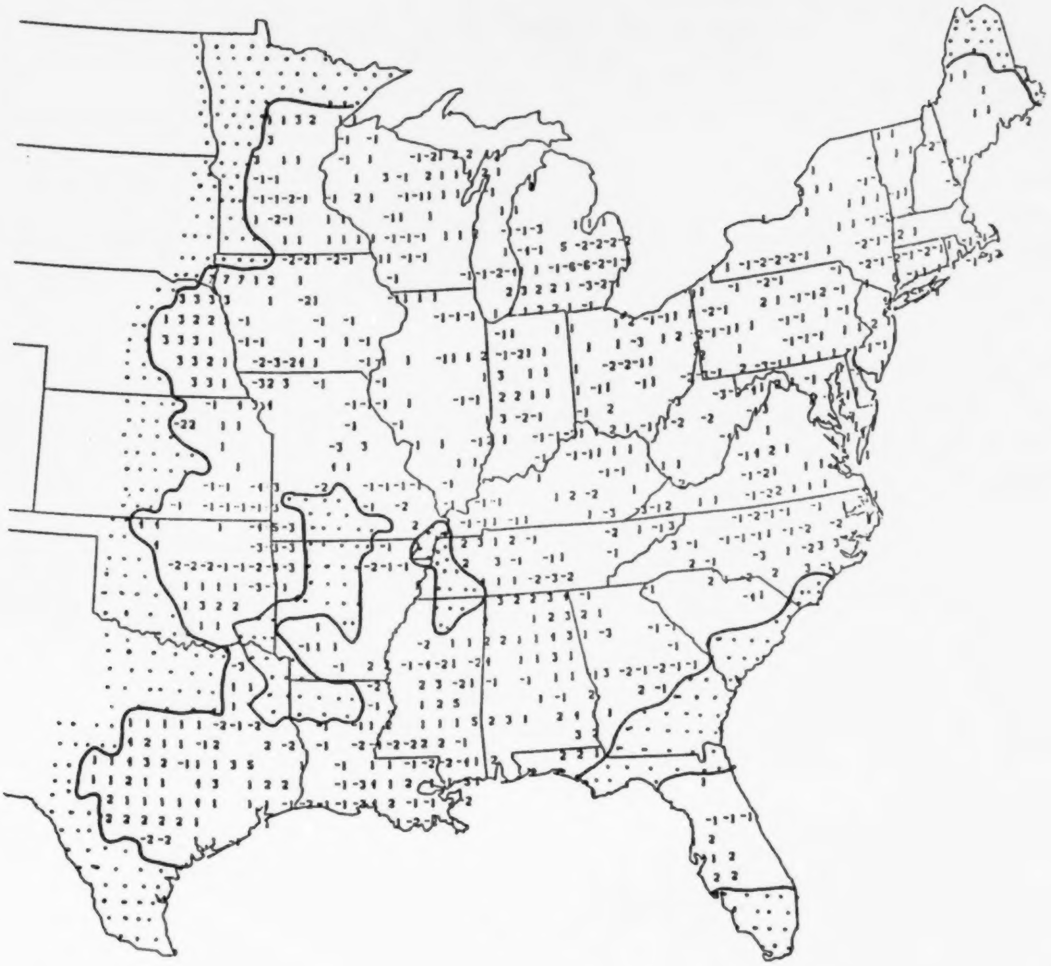


Figure 6.4.16. Cell by cell differences between Corrected Model and Ordinary Kriging Model (ppb), 1982. Note. Blank areas indicate that no ozone estimate was made due to insufficient data. Those areas covered with dots were not kriged.

The differences between the Ordinary Kriging Model and the NCLAN models are due to two factors. First, the variogram models used in the Ordinary Kriging Model are different than the ones used have in the NCLAN Models. The nugget effects used in the Ordinary Kriging Models were lower than nuggets in the NCLAN model. The lower nugget causes the estimates to be less averaged or smoothed and therefore, the estimates are able to follow the highs and lows in the data, particularly in the region of the country where there are closely spaced monitoring sites. Second, by using more data (up to the nearest 10 samples rather than the nearest five) to estimate a grid, different estimates would be anticipated.

6.4.6. Comparison of Kriged Estimates to Known Values

As described previously, the monitoring data used to construct the kriging estimates were obtained from State and Local Monitoring stations (SLAMS) archived in the EPA SAROAD data base. Other monitoring data have been collected that do not reside in SAROAD. The kriged 7-hr seasonal O_3 esimates were compared to O_3 data collected at rural locations.

Additional O_3 monitoring data were obtained from the Electric Power Research Institute (EPRI), Tennessee Valley Authority (TVA), the U.S. National Park Service, and several NCLAN investigators. The 7-hr O_3 concentration for May through September was calculated at each site using the hourly mean data. While the quality of the data has been reviewed by each of the investigators, it is unknown if the data are of the same quality as those contained in the SAROAD data base.

The results of the comparison of the kriged estimates to the known sites are listed in Table 6.4.8. The estimated 7-hr, 5-month seasonal O_3 values calculated using the 'Corrected Model' were, on an average, 13 ppb lower than the values experienced at the EPRI SURE/ERAQS monitoring sites (Table 6.4.8.). Using all data provided in Table 6.4.8., in 25 of 33 cases (76%), the (1) 'Original Model' and (2) 'Corrected Model', using 5 nearest neighboring sites, underestimated the actual 7-hr seasonal concentration. The 'Ordinary Kriging Model' (using 1979 and 1982 data) underestimated 13 of the 16 cases (81%) (the Olympic, Washington and Shafter, California sites were not included in the Ordinary Kriging run). Using the actual measured concentrations for all monitoring sites, the average concentration was 50 ppb (Table 6.4.8.). Data in the table show that the average of the estimated 7-hr concentrations, using any of the kriged models, was approximately 44 ppb. There is an indication of bias even though a small number of monitoring sites were used in the validation analysis. Additional consideration should be given to improving the selection of monitoring sites to be included in the future kriging analyses.

6.5. CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be derived from this study.

1) The original kriging program used by NCLAN incorrectly calculated the diagonal elements of the kriging equations. This error, however, did not result in gross errors in the kriged estimates. When

Table 6.4.8. The comparision of reported versus predicted 7-Hr values (ppb).

Data Base	Site Name	Year	Months	Act.	Orig. Model		Corr. Model		Ord.Krig.Model	
				7-Hr	7-Hr	2-SDV	7-Hr	2-SDV	7-Hr	2-SDV
EPRI	Montague, MA	1978	May-Sep	54	42	9.04	42	9.32		
EPRI	Indian River, DE	1978	May-Sep	60	41	9.71	40	9.98		
EPRI	Rockport, IN	1978	May-Sep	58	48	9.29	48	9.58		
EPRI	Research Tri. Park, NC	1978	May-Sep	69	53	9.86	53	10.13		
EPRI	Lewisberg, WV	1978	May-Sep	58	44	9.40	44	9.69		
NCLAN	Raleigh, NC (SERCLAP)	1978	May-Sep	58	53	9.86	53	10.13		
EPRI	Montague, MA	1979	May-Sep	54	45	8.15	46	8.47	44	9.31
EPRI	Scranton, PA	1979	May-Sep	54	40	9.15	40	9.57	41	10.61
EPRI	Indian River, DE	1979	May-Sep	52	44	10.42	44	10.64	43	12.30
EPRI	Duncan Falls, OH	1979	May-Sep	50	36	9.63	37	9.89	37	11.02
EPRI	Rockport, IN	1979	May-Sep	47	40	7.29	40	7.79	40	6.64
EPRI	Research Tri. Park, NC	1979	May-Sep	55	38	10.08	38	10.31	42	11.92
EPRI	Lewisberg, WV	1979	May-Sep	50	35	9.38	36	9.69	38	11.09
TVA	Saltillo, TN	1979	May-Sep	43	38	10.21	37	10.45	39	11.98
NCLAN	Raleigh, NC (SERCLAP)	1979	Jun-Sep	51	38	10.08	38	10.31	42	11.91
TVA	Murphy Hill, AL	1980	May-Sep	61	51	9.32	50	9.71		
NCLAN	Argonne, IL (CSRCLAP)	1980	Jul-Sep	50	43	7.68	43	8.12		
NCLAN	Raleigh, NC (SERCLAP)	1980	Jun-Sep	56	63	8.69	62	9.11		
NCLAN	Boyce Thomp. Ins., NY	1980	Aug-Sep	37	40	8.75	40	9.18		
TVA	Murphy Hill, AL	1981	May-Sep	49	55	7.49	55	7.49		
NCLAN	Argonne, IL (CSRCLAP)	1981	Jun-Sep	43	40	6.94	40	6.94		
NCLAN	Raleigh, NC (SERCLAP)	1981	Jun-Sep	51	50	7.14	50	7.14		
NCLAN	Boyce Thomp. Ins., NY	1981	Jul-Sep	33	38	7.37	38	7.37		
NCLAN	Shafter, CA (SWRCLAP)	1981	Jan-Oct	77	58	8.62	58	8.62		
TVA	Murphy Hill, AL	1982	May-Sep	56	55	8.34	55	8.69	51	10.84
NPS	Grand Canyon NP, AZ	1982	Jun-Sep	43	45	9.98	45	10.22	47	13.05
NPS	Congaree Swamp, SC	1982	May-Sep	22	49	7.28	49	7.84	48	9.15
NPS	Gr. Smokey Mts NP, TN	1982	May;Jul-Sep	47	48	7.46	49	7.99	48	9.51
NPS	Olympic NP, WA	1982	May-Sep	19	28	9.43	28	9.75		
NCLAN	Shafter, CA (SWRCLAP)	1982	Jun-Oct	47	41	8.87	42	9.14		
NCLAN	Argonne, IL (CSRCLAP)	1982	May-Sep	43	40	5.95	39	6.49	40	4.43
NCLAN	Raleigh, NC (SERCLAP)	1982	Jun-Sep	51	45	6.89	43	7.41	46	7.92
NCLAN	Boyce Thomp. Ins., NY	1982	May-Oct	41	35	6.81	36	7.40	36	8.55
Average				50	44		44		43	

compared to estimates prepared with the corrected program, between 85 and 90% of the cell estimates were identical.

2) The experiments performed in this study show that by including the city-center sites originally excluded, the kriged estimates were slightly lowered. These results complemented the validation analyses. Using actual 7-hr seasonal values derived from monitoring data not included in the original data base, the validation analysis showed an underestimation of 7-hr seasonal O_3 concentrations.

3) The kriging estimates can be improved by performing a more comprehensive variogram analysis. In particular, the original study used one variogram model to describe the spatial characteristics of 7-hr seasonal O_3 concentrations for the entire United States. By partitioning the United States into several homogeneous zones, and then analyzing each independently, the kriging model can be significantly improved. By using more data in the kriging estimates (e.g., using the closest 10 or 15 monitoring sites rather than the nearest 5), the estimates could be improved.

Most of the data are not derived from rural monitoring sites and the use of urban monitoring sites that are not representative of rural areas to estimate rural O_3 7-hr seasonal values may lead to biased estimates. Ozone data that are truly representative of agricultural areas and have gone through an accepted quality assurance program should be used in the kriging model. To date, the data used have not been adequately screened. Care should be taken to only exclude from the data set monitoring sites that are not agriculturally relevant.

ACKNOWLEDGEMENT

We wish to acknowledge the cooperation and assistance of Mr. James Reagan, EPA, Research Triangle Park, NC. The information he provided allowed the Panel to perform its analyses in a timely fashion. The Electric Power Research Institute, Tennessee Valley Authority, National Park Service, and the NCLAN investigators are acknowledged for providing air quality data. Montana State University's Center for Data Systems and Analysis is acknowledged for its assistance in characterizing the EPRI, TVA, and National Park Service air quality data. The assistance of the Oak Ridge National Laboratory is acknowledged for providing photographs of the 7-hr seasonal kriged values as reported by Mr. James Reagan for 1978 through 1982.

SECTION 7

AN ESTIMATION OF THE IMPACT OF REGIONAL MOISTURE STRESS ON THE O_3 SENSITIVITY OF THE 1980 U.S. SOYBEAN CROP (NWRCLAP)--David A. King

7.1. INTRODUCTION

Recent estimates of crop losses due to ambient O_3 are based on the results of fumigation experiments performed on adequately watered crops (42). However, drought frequently affects crop growth (43) and moisture stress retards the appearance of O_3 damage under laboratory (44) and field conditions (45). To evaluate the water stress x O_3 interaction, a crop water use and yield model was constructed, based on current knowledge of crop responses to O_3 and drought. The model calculates dry matter yield as a product of seasonal transpiration and transpiration efficiency (yield/transpiration) and is designed to estimate regional O_3 x drought interactions, given appropriate weather, O_3, and soils inputs.

The O_3 x moisture stress model is based on the observation that dry matter production is generally proportional to seasonal transpiration for a given cultivar, location, and year (46). This relationship may be modified by O_3 damage which reduces both transpiration and transpiration efficiency (47). If transpiration efficiency (TE) is defined as

$$TE = Y/ST \tag{1}$$

where Y is dry matter production and ST is seasonal transpiration, then dry matter yield can be expressed as

$$Y = ST \cdot TE \tag{2}$$

and the relative yield associated with a given pattern of rainfall and O_3 exposure can be written as

$$Y/Y_p = (ST/ST_p) \cdot (TE/TE_p) \tag{3}$$

where Y_p, ST_p, and TE_p, respectively, denote the potential yield, seasonal transpiration, and transpiration efficiency of a crop experiencing no limitation by soil water or O_3.

Seasonal transpiration is calculated as the sum of daily transpiration which is in turn simulated as a function of pan evaporation, modified by crop growth stage, soil moisture, and O_3 damage. Transpiration efficiency is assumed to decline with cumulative O_3 exposure and moisture stress is assumed to reduce the effects of O_3 on both transpiration and transpiration efficiency. The model, described in detail by King (48), was calibrated for soybeans. However, it may be adapted to other crops by choosing the appropriate relationship between transpiration and pan evaporation and adjusting the modeled crop response to O_3.

Model results to date suggest that moisture stress frequently reduces the impact of O_3 on regional crop yield (48). However, a source of uncertainty involves the estimation of the crop response to moisture stress. To address this uncertainty, one would like independent estimates of the regional yield response to moisture stress. Several firms have developed the capacity to forecast regional crop yield from weather and soil moisture conditions. One of these firms, Control Data Corporation (CDC), was contracted to provide estimates of regional crop yields with and without moisture stress effects. CDC also provided weather and soils data and estimates of planting and maturity dates. Thus, the O_3 x water stress interaction model described by King (48) could be run with CDC inputs and the resulting drought effects compared with the drought effects estimated by CDC.

This report presents a comparison of the yield responses to moisture stress predicted by the CDC model and King's model with CDC inputs. A second objective is to estimate regional drought stress x O_3 interactions for the 1980 U.S. soybean crop. These estimates were obtained by using the drought impacts predicted by CDC in combination with the general relationship between yield sensitivity to O_3 and drought severity derived from the O_3 x moisture stress model.

7.2. METHODS

7.2.1. Simulation Procedure

Relative soybean yields for 1980 were simulated using an earlier version of the model specified by King (48). The parameters of this model were adjusted to approximate the soybean O_3-response relationship determined by Heck et al. (49) for adequately watered soybeans.

Moisture stress effects are modeled in terms of the amount of water in the wettest soil layer accessed by roots. The ratio of moisture stressed transpiration to nonstressed transpiration, T_o/T_p, is defined on a daily basis as

$$\begin{aligned} T_o/T_p &= 1, && \text{when } SW/PSW \geq B \\ \text{and } T_o/T_p &= (1/B) \cdot SW/PSW, && \text{when } SW/PSW < B \end{aligned} \tag{4}$$

where SW is plant available water in the wettest soil layer, PSW is potential available water for the same layer (soil water content as field capacity minus soil water content at the permanent wilting point), and B is the value of SW/PSW at which soil water becomes limiting. King (48) set B = 0.5 following Hank's (50) procedure for modeling yields of variably irrigated fields. However, B was set equal to 0.7 to increase the model response to moisture stress for the results presented here. This increase in model sensitivity to moisture stress was also found to be necessary by Holt (Univ. of Illinois, personal communication) in modeling large area crop yields.

The O_3 x water stress model was run for approximately every other crop reporting district over the major soybean producing areas of the U.S. using 1980 weather and soils data provided by CDC. One or two representative well drained soil types and one or two poorly drained soil types were identified by CDC for each crop reporting district. As the interaction model was constructed for adequately drained soils, only the well-drained soils data were used in the results presented here. For each district simulated, a SAROAD O_3 monitoring station was identified from the set of stations used by Reagan (51) to estimate regional mean O_3 concentrations for 1980. Monitoring stations ranged in distance from within the district in question to 250 km from its border. Hourly O_3 values were input to the model and missing values were replaced with corresponding hourly means for the month in question. The model was then run with the CDC daily pan evaporation and rainfall data plus ambient, sub-ambient and super-ambient O_3 values. Similar runs were made with soil moisture set equal to field capacity to provide no-water-stress comparisons.

7.2.2. Estimation of Regional Moisture Stress Effects on Soybean Yields

A model for simulating county level soybean yields was developed by Purdue University in cooperation with Control Data Corporation (52). The general approach used in constructing the model is described by Holt et al. (53). To forecast yields this model computes a weather factor which reduces the expected maximum yields of a county or crop reporting district with the occurrence of suboptimal weather and soil moisture conditions. This weather factor is computed as the summed product of a daily weather index and a growth stage weighting factor (52). The weather factor incorporates known physiological principles and was calibrated to produce accurate estimates of regional yields. Soil moisture effects are incorporated into the daily weather index through a soil moisture factor which is computed from the daily soil water contents predicted by the soil moisture model of Dale et al. (54).

The large area model was run by CDC with 1979 through 1983 weather data from the major U.S. soybean, corn, and wheat producing areas, but only the 1980 soybean results are presented here. Yields and seasonal evapotranspiration were simulated by CDC for the above-calculated daily soil moisture deficits and for moisture deficits set equal to zero. Soybean yields were simulated within the 14 states which contributed 89% of the 1980 U.S. soybean crop. Yields were reported in bushels per acre (rounded to the nearest bushel) for moisture stressed and nonstressed conditions for each crop reporting district.

7.3. RESULTS

7.3.1. Predicted Moisture Stress Impacts on O_3 Sensitivity of Soybeans

Reductions in yields due to moisture stress (at ambient O_3 levels) were predicted by the O_3 x water stress model for 49 of the 53 subregions modeled. The mean drought depression of yield was 10% when all model runs were weighted equally. The modeled crop response to O_3 was reduced whenever simulated ambient yields were depressed by moisture stress. Moisture stress correction factors (F) were computed as

$$F = \frac{\Delta Y/Y}{\Delta Y_p/Y_p} \qquad (5)$$

where Y is predicted yield with actual rainfall and ambient ozone, Y_p is the yield at ambient O_3 with no moisture stress and ΔY and ΔY_p, respectively, denote the change in moisture stressed and nonstressed yields caused by a 25% departure from ambient O_3 levels. The correction factors were defined in this fashion so that they could be used in the economic assessment to correct the crop response derived from adequately watered exposure-response functions (see Section 8). Shifts in ambient O_3 of ± 25% were typical scenarios analyzed by the economic modelers (42).

The magnitude of F was closely related to the relative yield reduction due to moisture stress and was fitted to the normalized Weibull function

$$F = e^{-(x/\sigma)^c} \tag{6}$$

with $\sigma = 0.527$ (se = 0.048), and $c = 0.724$ (se = 0.048, RMS = 0.0016, N = 49), where x is the fractional yield reduction due to moisture stress. This Weibull function relationship is shown in Fig. 7.1.

7.3.2. Moisture Stress Impacts on 1980 Soybean Yields Predicted by CDC

Noticeable declines in soybean seed yield due to moisture stress were predicted for 46 of the 75 crop reporting districts modeled by CDC, and slight declines in seasonal evapotranspiration were estimated for most districts showing no changes in per acre yield rounded to the nearest bushel. The ratio of moisture stressed yield to nonstressed yield (relative yield) was highly correlated with relative evapotranspiration ($r = 0.86$, $n = 75$). Relative yield was somewhat more sensitive to regional moisture stress than was relative evapotranspiration (ET) as indicated by the regression relationship

$$\text{Rel yield} = -0.240 + 1.234 \text{ Rel ET}.$$

The relative yields and evapotranspiration predicted by CDC were compared to predictions of the O_3 x water stress model for those crop reporting districts for which weather data were provided and for which well drained soils comprised more than 2/3 of the district. The latter restriction was employed because the interaction model was only run for the well-drained fraction of each crop reporting district. The relative yields of the interaction model were highly correlated with the relative evapotranspiration predicted by CDC ($r = 0.88$, $n = 12$). The mean relative yield of 0.855 was similar to the mean relative evapotranspiration of 0.846 estimated by CDC for the same 12 districts, and the regression relationship between the two was

$$\text{Rel modeled yield} = 0.326 + 0.626 \text{ Rel ET}.$$

The relative yields of the interaction model were also highly correlated with CDC relative yields ($r = 0.96$, $n = 12$), although the mean modeled relative yield (0.855) was higher than the mean CDC relative yield of 0.768, and the regression relationship between the two was

$$\text{Rel modeled yield} = 0.470 + 0.501 \text{ Rel CDC yield}.$$

Modeled relative yields are plotted vs CDC relative yields in Fig. 7.2. The mean drought impact shown in the figure was higher than mean impact for all crop reporting districts, reflecting the selection of districts with well-drained soils.

7.3.3. Moisture Stress Correction Factors for Soybeans

The relative yield decreases calculated by CDC were inserted into equation 6 to compute moisture stress correction factors for each crop reporting district. These district level correction factors were then weighted by soybean production in each district to produce the statewide correction factors shown in Table 7.1. Correction factors for the 1980 soybean crop ranged from 0.45 for Kansas to 1.0 (no moisture stress effects) for Ohio and Michigan, with an overall weighted average of 0.81.

7.4. DISCUSSION

The CDC soybean model is designed to predict seed yield and has been validated at the county level. Thus, CDC estimates of relative yield may be viewed as the best available approximations of moisture stress effects on regional soybean production. The high correlation between relative yields predicted by the O_3 x moisture stress interaction model and those predicted by CDC suggests that the interaction model encompasses the major processes by which drought limits yield. However, the interaction model tended to underestimate 1980 moisture stress impacts on seed yield, particularly for areas experiencing severe drought. The yield response to drought calculated by CDC also tended to exceed the evapotranspirational response. As most evapotranspiration occurs as transpiration during the growing season, it is possible that drought affected seed yield more than seasonal transpiration for many of the crop reporting districts. The tendency of the interaction model to underestimate drought impacts on seed yield may thus be due to the model assumption that yield is proportional to transpiration at a given level of O_3 damage. While this assumption may be adequate for dry matter production, seed yield is known to depend on the timing of drought as well as on seasonal transpiration (46).

Moisture stress impacts on yield estimated by CDC were used in combination with the O_3 sensitivity-moisture stress relationship derived from the interaction model to calculate regional moisture stress correction factors to the O_3 exposure response for soybeans. This approach was taken to avoid the above biases in the estimation of regional moisture stress effects and allows the analysis to be extended to poorly drained soils, which comprise a substantial fraction of the soybean production area (54). However, the model and the above extension of it have not been validated with field experiments. Moisture stress reduced O_3 impacts on cotton fumigated in California (10) but results to date for soybean are inconclusive (55,56).

The correction factors listed in Table 7.1. suggest that moisture stress frequently reduces the impact of O_3 on regional soybean yields. A preliminary analysis of CDC yield estimates for other years indicates that the mean moisture stress impacts reported for 1980 may be typical, although the pattern of drought across the region is expected to vary substantially from year to year.

Table 7.1. Calculated mean impacts of moisture stress on yield and on yield sensitivity to O_3 for soybeans grown in 1980.

State	Mean relative yield	Mean moisture stress correction factor	1980 production in millions of bushels
AR	0.88	0.71	65
IL	0.98	0.94	310
IN	0.99	0.98	158
IA	0.87	0.76	318
KS	0.60	0.45	24
KY	0.75	0.57	37
LA	0.92	0.90	70
MI	1.00	1.00	30
MN	0.83	0.67	152
MO	0.79	0.62	135
MS	0.95	0.85	62
NB	0.76	0.60	53
OH	1.00	1.00	135
TN	0.81	0.63	48

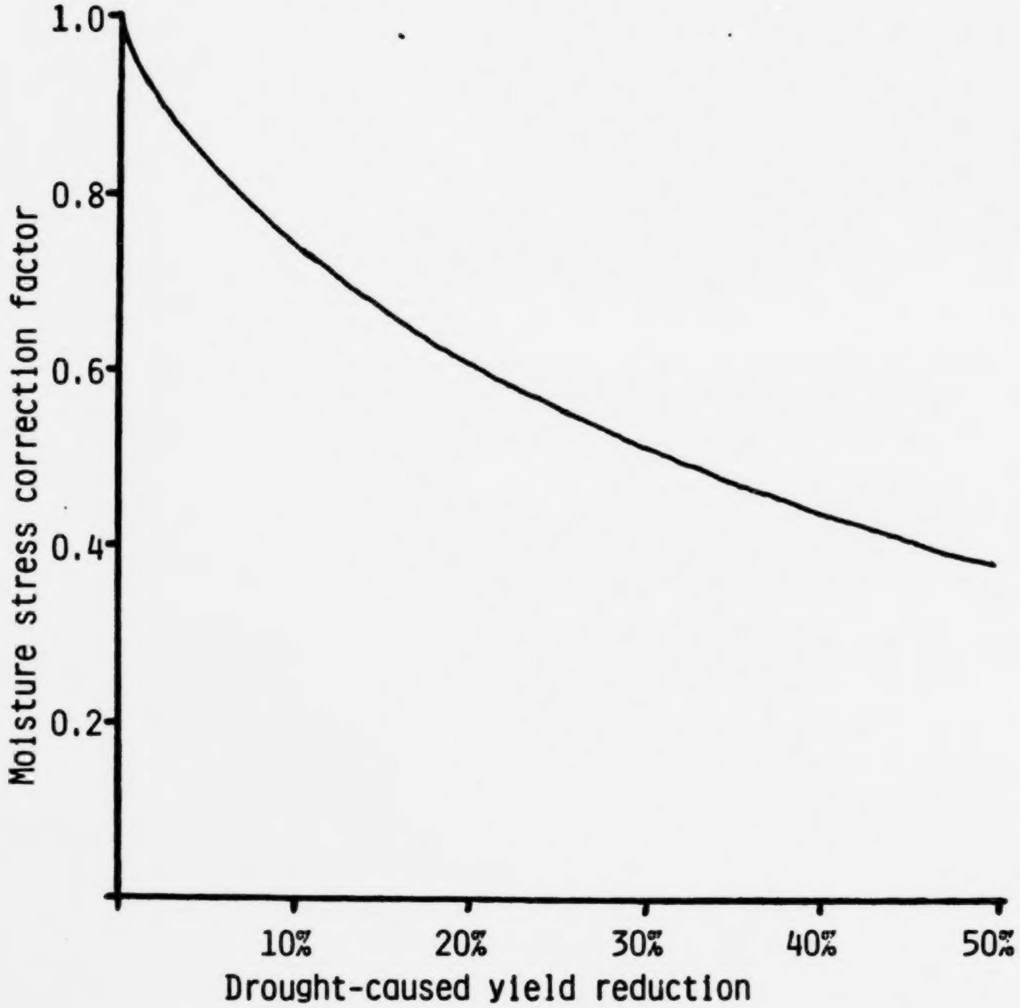


Figure 7.1. Weibull function relationship between the moisture stress correction factor and drought depression of yield derived from 1980 simulations with the moisture stress x O_3 interaction model.

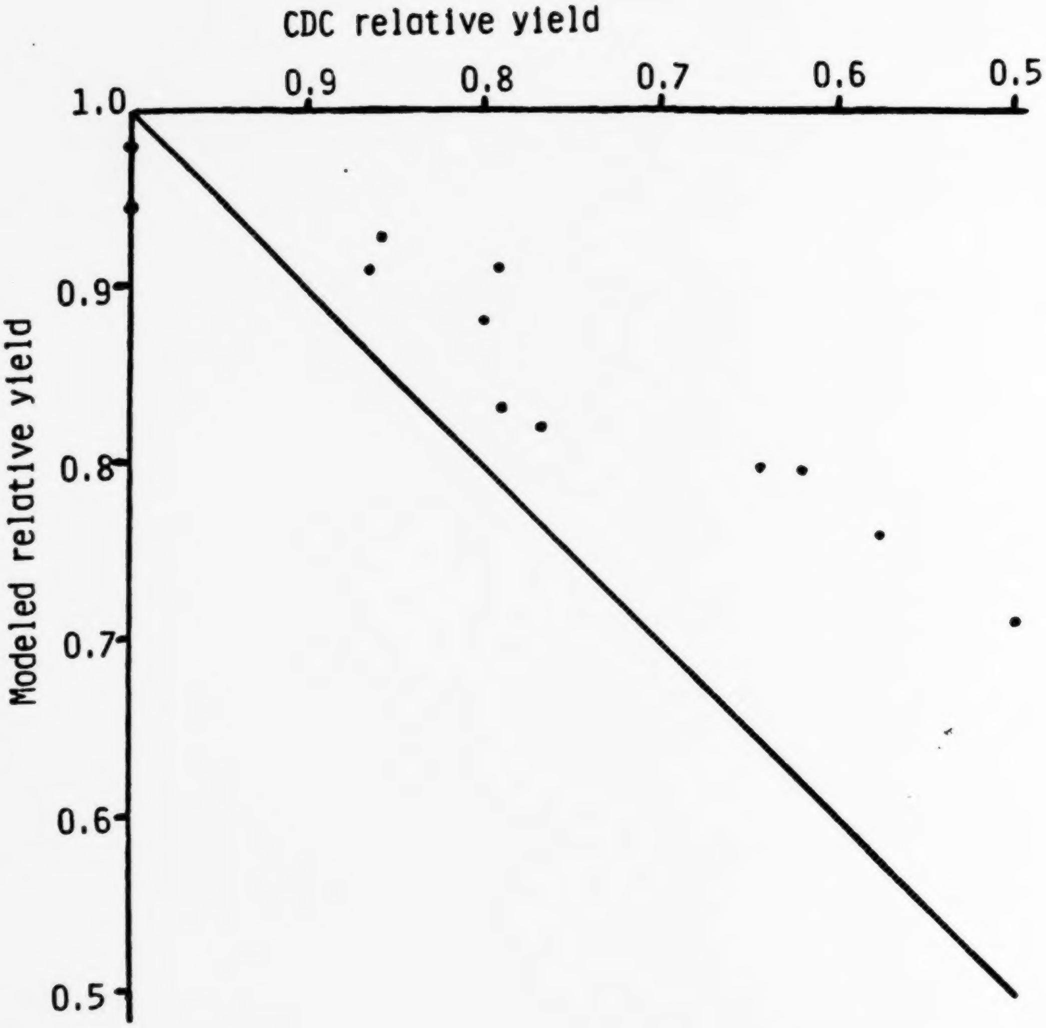


Figure 7.2. Relative yield predicted by the moisture stress x O_3 interaction model vs relative yield estimated by Control Data Corporation for crop reporting districts with mostly well-drained soils. Relative yield is defined as the ratio of actual yield to no-water stress-yield under ambient ozone conditions. The diagonal line indicates equivalent relative yields.

SECTION 8

PRELIMINARY ASSESSMENT (1984) OF THE ECONOMIC CONSEQUENCES OF O_3 ON U.S. AGRICULTURE (NWRCLAP)--Richard M. Adams, Bruce A. McCarl

8.1. BACKGROUND/OBJECTIVES

One of the primary objectives of the National Crop Assessment Network (NCLAN) is the estimation of the national economic benefits to agriculture and its constituents of reductions in ambient O_3. From the outset of the NCLAN program in 1981, it was recognized that achievement of this goal would involve a multi-year effort, given the time required to generate requisite plant science data. Thus, during 1982 and 1983, the economics program focused on identification, development and implementation of an appropriate assessment framework to be used when a sufficient plant science database became available. Alternative methodologies were tested in several regional benefit assessments. The 1982 and 1983 NCLAN Annual Reports (41,57) summarize this initial phase of the economic program. By 1984, sufficient plant science data were available to perform the preliminary assessment of these benefits, using the economic assessment framework developed in 1983.

It is the purpose of this section to report on that preliminary national economic assessment of O_3 effects on agriculture. The analysis, data and results underlying this assessment represent the collective plant science, meteorological and economic knowledge gained from the NCLAN program through 1983. The results are derived from an economic model of the U.S. agricultural sector [adapted from Chattin et al. (58)]. Empirical emphasis is on six major crops (corn, soybeans, wheat, cotton, grain sorghum, barley) which account for over 75 percent of U.S. cropped acreage (59). Possible O_3 effects on hay are also evaluated using average response of other crops as a surrogate. NCLAN yield response data through the 1983 growing season suggest likely changes in crop yields due to hypothetical changes in ambient O_3. These crop yield responses are then used to modify the economic model to derive estimates of the benefits of alternative ambient O_3 levels. In addition to measuring the effects on each crop, the assessment accounts for the linkage between feed grains, such as corn, and livestock, by including a livestock production and feeding component, as well as economic effects through export markets for major agricultural commodities. The approach and results of the analysis are highlighted in the following sections abstracted from the final project report to EPA by Adams et al. (42). More detail on procedure, data and results is available in that report.

8.2. APPROACH

The analysis and methodology used in the assessment are conceptually similar to the numerous induced change analyses found in the agricultural economics literature. Implementing the assessment methodology for the case of O_3 was done using both detailed farm level models and a sector model to capture aggregate or national level effects. The farm level models provide input for the agricultural sector model which measures the aggregate economic effects of O_3. Specifically, the sector model component is a price-endogenous mathematical programming model of the agricultural sector (60) (i.e., both prices and quantities for each commodity are generated by the model solution). Such sector models have been used extensively by agricultural economists to simulate the effect of alternative agricultural policies or technological change (61,62). Among the various methodologies available to formulate policy models, mathematical programming has proven to be a particularly useful tool given its ability to predict potential consequences of as yet unrealized policies. This general methodology has been applied to air pollution effects in a number of recent regional studies (63-66).

Data for the sector model were provided in part by the models which were used to model producer behavior. Linear programming (LP)-based farm models (67) were implemented for representative farms in the Corn Belt. For areas outside the Corn Belt, historical data were used to generate whole farm plans. Crop records by state for 1970-1981 were used to develop representative state level crop mixes and to econometrically derive estimates of crop yield changes when crop mix changes. These whole farm plans from both sources were then used to pregenerate a number of cropping activities for the sector model utilizing the USDA FEDS budgets. The economic model used in the assessment is thus a sector model using data generated by the farm models or historical data following the procedures in McCarl (68). More technical data on the model is available in Adams et al. (42) and in the 1983 NCLAN annual report (57).

The economic model, when perturbed to reflect alternative O_3-induced yield changes, generates estimates of the economic effects due to these O_3 changes. Each of a series of hypothetical O_3 scenarios is judged against a 1980 base solution. The difference between the base solution (reflecting 1980 parameters) and the hypothetical O_3 analyses gives an estimate of the social benefits or costs of the O_3 change.

A plausible solution is established for a base case; then the model is solved using alternative yield values (modified from actual 1980 yields) that reflect hypothetical O_3 levels in each production area (state or sub-state levels). The yield adjustments are derived by use of a mix of NCLAN response functions applied to the O_3 levels. In this analysis four alternative O_3 levels are evaluated which represent: 10, 25, and 40 percent reductions in ambient O_3 concentrations and a 25 percent increase in O_3 (from 1980 and 1978-82 mean levels).

Within the NCLAN data there are numerous cultivars (varieties) of certain crops on which to base yield adjustments for use in the economic analysis. Screening of the multiple cultivar data indicates that a common or "pooled" response model estimated across cultivars is appropriate for some crops (56). For other crops, only one cultivar is available in the NCLAN data. Specifically, pooled response models are available and appropriate for corn, soybeans and wheat, in combination with two cultivars of cotton (irrigated and nonirrigated) and individual cultivars of grain sorghum and barley. Using different combinations of response functions drawn from this set, the four O_3 alternatives are then translated into corresponding yield changes. The economic effects of the four alternative

O_3 scenarios are evaluated by solving the economic model under each yield change.

Five distinct analyses are performed, each within the four alternative O_3 levels. The five analyses are summarized in Table 8.1. Analyses I and II use various combinations of pooled responses for certain crops in addition to the single cultivar crops. Analysis I uses response functions estimated across all statistically similar cultivars grown in a given region. In the pooled analyses, a few cultivars are not included because of their heterogeneous nature. An analysis based on these more extreme responses can serve to place some bounds on the assumed "more representative" responses captured in Analyses I and II. Analysis III thus uses the single cultivars available for barley and sorghum in combination with the nonheterogeneous cultivars of corn, soybeans, wheat and cotton.

Analyses IV concerns the ambient level of O_3 used in the assessment. The assessment required a base O_3 level for use in the calculation of yield changes. Since the economic model is calibrated to 1980, 1980 O3 levels are a logical benchmark for use in the hypothetical O_3 analyses. These 1980 values underlie Analyses I, II and III. However, annual variation in seasonal O_3 levels is high, amounting to 40 percent in some areas. As an alternative, the years from 1978 to 1982 are averaged and the average values are used as a second characterization of base O_3 levels. These new ambient O_3 levels for each region are then used to evaluate the four O_3 situations (i.e., the 10, 25, and 40 percent changes are now calculated relative to the alternative O_3 base level). The response functions used in the evaluation are those for the first analysis (the national pooled responses). This set of four model solutions is identified as Analysis IV.

Finally, Analysis V focuses on potential interactive stresses. That is, the presence of drought or moisture stress within individual NCLAN field plots has been shown to reduce the effects of O_3 on crop yield in some instances [e.g., Temple et al. (10)]. Thus, it is possible that if plants are drought stressed during high O_3 levels, the effects of O_3 as predicted by controlled experiments when plants are well-watered, may either overstate or understate the effects of O_3. This possibility has important implications in a national assessment, where from 50 to 90 percent of the acreage of major crops are grown under nonirrigated conditions. Ideally, response functions that reflect the O_3-water stress interactions could be used in combination with some meso-scale drought data to more accurately assess the economic effects of O_3 under real world conditions. Unfortunately, such an interactive response data set does not currently exist. However, limited data are available on O_3-water stress interactions from three NCLAN experiments. An NCLAN plant simulation model provides an additional estimate of the effect of water stress on O3 effects (48). The results of these studies can be used to provide some crude quantitative adjustments to the fully watered response functions generated from NCLAN data. Using these limited observations, a fifth and highly exploratory analysis (Analysis V) examines the effect of O3 effects on crops in the presence of water stress.

Table 8.1. Summary of alternative assessment analyses: cultivar, O_3 and stress assumptions.

Analysis	Cultivar Mix	Ambient O_3	Moisture Stress	Evaluation
I	Pooled response of all homogeneous cultivars for soybeans, corn, wheat, cotton; individual cultivars for barley and sorghum. Hay response measured as average of other crops.	1980 seasonal average	Not treated	Pooled analysis based on all homogeneous cultivars. This analysis is intended to minimize extrapolation bias between sites and broad-scale assessments. Includes "with" and "without" hay adjustment analyses.
II	"Regionalized" pooled response for homogeneous cultivars of soybeans and corn. Wheat and cotton is in Analysis I. Individual cultivars for barley and sorghum. Hay measured as surrogate response.	1980 seasonal average	Not treated	Analysis based on pooled data for homogeneous cultivars common to a given region.
III	Individual cultivars for all crops. Cultivars for corn, wheat, soybeans and cotton represent extreme yield effects in NCLAN data set. Hay measured as surrogate response.	1980 seasonal average	Not treated	Extreme analysis to test the sensitivity of the economic estimates to the maximum variability in cultivar response information.
IV	Same as found in Analysis I.	Average of 1978-1982 seasonal average	Not treated	Analysis tests the effect of O_3 years(s) on estimates; smooths out variability in annual O_3 levels.
V	Same as found in Analysis I.	Same as Analysis I	Adjusted on basis of NCLAN moisture stress experiments and crop simulation model and 1980 1980 rainfall.	Preliminary attempt to adjust for moisture stress; serves to suggest possible bias in analyses that ignore other stress factors.

These five analyses, in combination with the four O_3 levels and the base case, result in 21 distinct evaluations using the economic sector model formulation. Analysis I generates an overall impression of O_3 effects. Analyses II through V are analyses of the sensitivity of the economic estimates to varying yield assumptions. The results of all these analyses, as measured by a range of economic effects including aggregate economic effects on producers and consumers, provide a detailed characterization of the probable economic effects of O_3 on agriculture under a range of data conditions.

8.3. RESULTS

The results obtained with the economic base model are evaluated by comparison with actual values realized in 1980. The base model outputs of primary concern are the equilibrium prices and quantities for included crops and livestock products. The values of these variables, derived endogenously in the model solutions, are those which optimize the mathematical problem inherent in the model specification. Validation of these values against actual 1980 levels establishes the general performance of the model.

A comparison of base model results and actual values is presented in Table 8.2. Overall, the prices and quantities are quite close to actual, with all model prices falling within 3 percent of actual. Quantities are generally within 10 percent of actual. Other model features, including the net social benefit estimates (objective function) and regional production patterns are also close to actual values for the base year. This validation of the general equilibrium model indicates that the base model is an accurate benchmark against which to gauge the economic effects of O_3-induced yield changes.

The results of Analysis I, as measured against the base case are reported in Table 8.3 and indicate that the benefits to society from O_3 reductions are substantial. The 10, 25 and 40 percent reductions in O_3 result in annual benefits of \$.669, \$1.712, and \$2.518 billion, respectively. A 25 percent increase in O_3 results in a loss (negative benefit) to society of \$2.096 billion. As percentages of the 1980 farm value of the included crops and livestock commodities, these economic estimates are 0.6, 1.6, 2.5 and 2.1 percent of that total. The average yield changes giving rise to these economic changes are 1.0, 2.5, 3.5, and 3.0 percent, respectively.

These estimates do not include yield adjustments for hay, an important crop in a national assessment because of its role in the feed-livestock balance. An exploratory analysis using Analysis I O_3 yield effects was also performed adjusting hay yields by the average of the other six crops. If hay yields are varied as O_3 changes, the corresponding results are \$0.756, \$1.937, \$2.859 and \$-2.363 billion. Thus, the hay effect is approximately 13 percent of the economic estimates.

Both consumers and producers benefit from the reduction of O_3 in this assessment. Consumers benefit from reduced prices arising from increased supplies. About 60 percent of the consumer benefits accrue to

Table 8.2. Actual and model 1980 prices and quantities for primary crops and commodities.

	1980 Prices		1980 Quantities	
Commodity	Model	Actual	Model	Actual
	($/unit)[a]		(million units)	
Cotton	366.72	358.00	17.45	15.65
Corn	3.25	3.11	7,339.85	6,645.84
Soybeans	7.74	7.57	1,778.07	1,792.06
Wheat	3.71	3.91	2,633.94	2,374.31
Sorghum	3.00	2.94	700.88	579.20
Rice	12.79	12.80	164.78	146.15
Barley	2.91	2.85	335.50	360.96
Oats	1.93	1.79	472.91	458.26
Silage	19.46	NA	91.24	110.97
Hay	70.90	71.00	141.58	131.03
Soybean Meal	0.11	0.11	46,180.80	50,624.00
Soybean Oil	0.24	0.23	10,755.81	11,270.00

[a] Units are as follows: 500-pound bales for cotton; bushels for corn, soybeans, wheat, barley, oats, and sorghum; hundredweight for rice; tons for hay and silage; pounds for soybean meal and oil.

Table 8.3. Annual economic effects of O_3 in $ 1980.

Ozone Assumption	Producer Surplus	Consumer Surplus	Total Surplus	Changes in: Producer Surplus	Changes in: Consumer Surplus	Changes in: Total Surplus
	$ billion					
Without Hay Adjustment						
Base	26.015	114.957	140.971	---	--	--
10% Reduction	26.250	115.390	141.640	0.235	0.433	0.669
25% Reduction	26.567	116.116	142.683	0.552	1.159	1.712
40% Reduction	26.788	116.701	143.489	0.773	1.744	2.518
25% Increase	25.413	113.462	138.875	-0.607	-1.495	-2.096
With Hay Adjustment						
Base	26.015	114.957	140.971	---	--	--
10% Reduction	26.337	115.389	141.727	0.322	0.432	0.756
25% Reduction	26.807	116.101	142.908	0.792	1.144	1.937
40% Reduction	27.271	116.559	143.830	1.256	1.602	2.859
25% Increase	25.122	113.486	138.608	-0.893	-1.471	-2.363

foreign consumers as manifested in export markets. Producers' benefits arise from the inclusion of the export and livestock sectors in the model. On a regional level, the producers in the Pacific (California), Delta, Northeast and Southeast regions experience the greatest relative gains from O_3 reductions. This is due to a combination of high ambient O_3 levels and a mix of O_3 sensitive crops (soybeans, cotton) in those regions, as well as some shifting of regional market shares at alternative O_3 levels.

The results of Analyses II through V provide some measure of the sensitivity of the economic estimates to assumptions concerning response and O_3 data. These quantitative results and additional discussion are contained in Adams et al. (42). Overall, Analysis II indicates that the difference between pooling cultivar data regionally, rather than across all cultivars, as in Analysis I, is small. This suggests that the response bias arising from aggregating statistically similar cultivars into one common response is minimal. Analysis III shows a much more dramatic difference in economic estimates when compared with Analysis I (approximately a 60 percent difference at each O_3 change). Analysis III uses the most extreme cultivar response available for soybeans, corn, wheat and cotton. Statistically and agronomically, however, these cultivar yield responses behave unlike the other NCLAN cultivars for those crops. As such, these economic estimates are perhaps upper bounds on potential impacts. Analysis IV demonstrates that the annual ambient O_3 levels used in the assessment do affect economic estimates but, like Analysis II, the difference is small (5 to 14 percent) between 1980 levels and a 5-year average. While not explored here, a more important issue may be the measure of dose (e.g., 7-hr or 12-hr) rather than variability in the measure. Finally, Analysis V represents an attempt to include drought stress in the O_3 assessment. Compared with Analysis I, the economic estimates are about 20 percent lower. This difference is important, in that water stress and other environmental interactions occur commonly under commercial agricultural production conditions. There are currently insufficient data to fully incorporate these stresses in economic assessments.

A number of limitations or caveats need to be attached to these estimates. While they are derived from a conceptually sound economic model and use the most recent supporting plant science and meteorological data in implementing that model, there are several sources of uncertainty. These include the issue of exposure dynamics (7-hr vs 12-hr), and the lack of environmental interactions in the response experiments. Each of these response issues is being addressed in current NCLAN research. Crop coverage in this assessment excludes crops comprising about 25 percent of U.S. acreage. While the addition of hay data in the 1986 assessment will increase coverage to about 90 percent, the exclusion of crops in the current assessment introduces a downward bias. Also, the O_3 data are based on a limited set of U.S. EPA's Storage and Retrieval of Aerometric Data (SAROAD) monitoring sites, mainly in urban and suburban areas. While the spatial interpolation process (kriging process) results in a fairly close correspondence between predicted and actual O_3 levels at a few validation points, the performance of the kriging process has not been fully validated. There is a need for more rural air quality monitoring sites and exploration of other procedures with which to develop ambient O_3 estimates for rural areas. Finally, the large scale economic model, with its many variables, parameters and the underlying data used to derive these values, is a potential source of uncertainty. For example, as presently structured, the economic model does not reflect changes in USDA farm programs that may accompany O_3-induced supply changes. Also, the model is a long-run equilibrium model and assumes that excess supply does not exist. The model was validated explicitly against historical values, and hence its policy utility is greatest when addressing changes bounded by historical levels, rather than adjustments outside the historical range. The modest yield and supply adjustments portrayed in the O_3 analyses fall within these historical levels.

8.4. PLANS FOR FUTURE ASSESSMENTS

The 1984 assessment is preliminary, in that uncertainties arise due to some aspects of the economic modeling approach and the incomplete nature of the yield response data. Research performed within the NCLAN program in 1984, 1985 and 1986 will be used to revise this assessment in 1987, using the biological knowledge gained from the 1984, 1985 and 1986 crop seasons. In addition, the economic model will be updated to reflect a different base period and may be modified to introduce some other economic dimensions, including the role of risk (due to O_3) in producer decision making.

In 1985, the effects of O_3 on crop yield variability and producer behavior will be investigated, first through development of a conceptual framework linking air pollution to producer decision-making in a stochastic environment and then empirically by estimation of yield variability under alternative environments as captured in the NCLAN and other data. This evidence, if significant, will be used to suggest the appropriate risk parameters to be introduced into the 1987 assessment. If ozone is observed to increase producer risk, the currently deterministic framework of the assessment model will be rendered stochastic with respect to expected income, which will allow the model to be optimized under conditions where both expected income and income variability of crop alternatives are evaluated. Finally, the model will be updated from the 1980 base period to a broader time base (e.g., 1981-83) to make the model more generalizable to a wider range of equilibria situations.

SECTION 9

NCLAN PUBLICATIONS

9.1 PUBLISHED

This section summarizes NCLAN publication status through September 1985. Keywords are shown in ( ) at end of citations. We have divided this section into:

Abstracts -	7
Inhouse and Other Reports -	20
Published Proceedings -	16
Journal Articles -	35

9.1.1. Abstracts

1) Admundson, R.G., R.J. Kohut, P.B. Reich, A.W. Schoettle, and R.M. Raba. 1984. Influence of O_3 and SO_2 on net photosynthesis, growth, and yield of *Triticum aestivum*. Bull. Ecol. Soc. Amer. 65:225.

2) Admundson, R.G. and P.B. Reich. 1985. Stomatal conductance as a predictor of O_3 effects on net photosynthesis, growth, and yield. Bull. Ecol. Soc. Amer. 66:89.

3) Heagle, A.S. 1985. Air pollution effects on peanuts. Peanut Disease Compendium, American Phytopathological Soc. Publication, St Paul, MN. p. 56. (O_3, Peanut, Yield)

4) Heck, W.W. 1984. Air quality and agricultural crops. Abstr. Presented at Annual Meeting of Agricultural Res. Inst. Oct. 8-10, 1984. (O_3, Crops, SO_2, NO_2)

5) Heggestad, H.E. 1983. Crop losses and air pollution. Environ. Sci. Technol. 17(1):6A.

6) King, D.A. 1984. Assessing the response of crops to ozone and drought. Bull. Ecol. Soc. Amer. 65:220. (O_3, Crops, Drought, Yield, Modeling)

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